Consortium for
Electricity
Reliability
Technology
Solutions

Dispatcher and Operating Engineering Security Applications Using Synchronized Phasor Measurements

DRAFT - FUNCTIONAL SPECIFICATION
For
SECURITY MONITORING PROTOTYPE WORKSTATIONS FOR DISPATCHERS AND OPERATING ENGINEERS USING SYNCHRONIZED PHASOR MEASUREMENTS

Version 1.0

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Transmission Reliability Program
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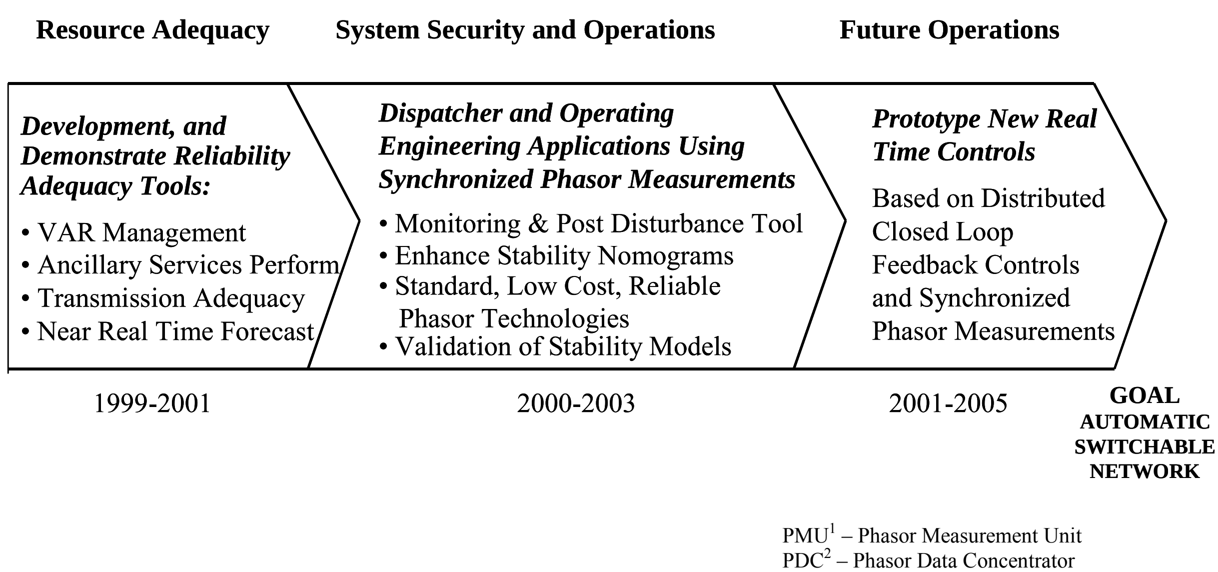
1. INTRODUCTION

The Consortium for Electric Reliability Technology Solutions (CERTS) has been formed to perform research, develop, and commercialize new methods, tools, and technologies to protect and enhance the reliability of the U.S. electric power system under the emerging competitive electricity market structures. The members of CERTS include Lawrence Berkeley National Laboratory (LBNL), Oak Ridge National Laboratory (ORNL), the Power Systems Engineering Research Consortium (PSERC), Sandia National Laboratories (SNL), Pacific Northwest National Laboratory (PNNL) and Electric Power Group (EPG). Southern California Edison (SCE) acts as a CERTS Research Provider.

CERTS is developing and demonstrating a series of modular, but integrated, computer based real time grid reliability management applications to assist the operating authorities (e.g. ISOs, RTOs, Security Coordinators) in their management of the grid.

Figure 1 shows CERTS incremental approach for developing, prototyping and demonstrating such applications with an ultimate goal to evolve and operate towards automatic switchable power networks. The first phase of the application series was to develop and demonstrate a PC-based workstations for VAR Management and Ancillary Services application prototypes for dispatchers, see left side from Figure 1. The second phase is to develop and demonstrate a security monitoring applications, designed for dispatchers and operating engineers, using Synchronized Phasor Measurements (SPM), see center from Figure 1.

Figure 1 - CERTS Incremental Roadmap Towards an Automatic Switchable Network



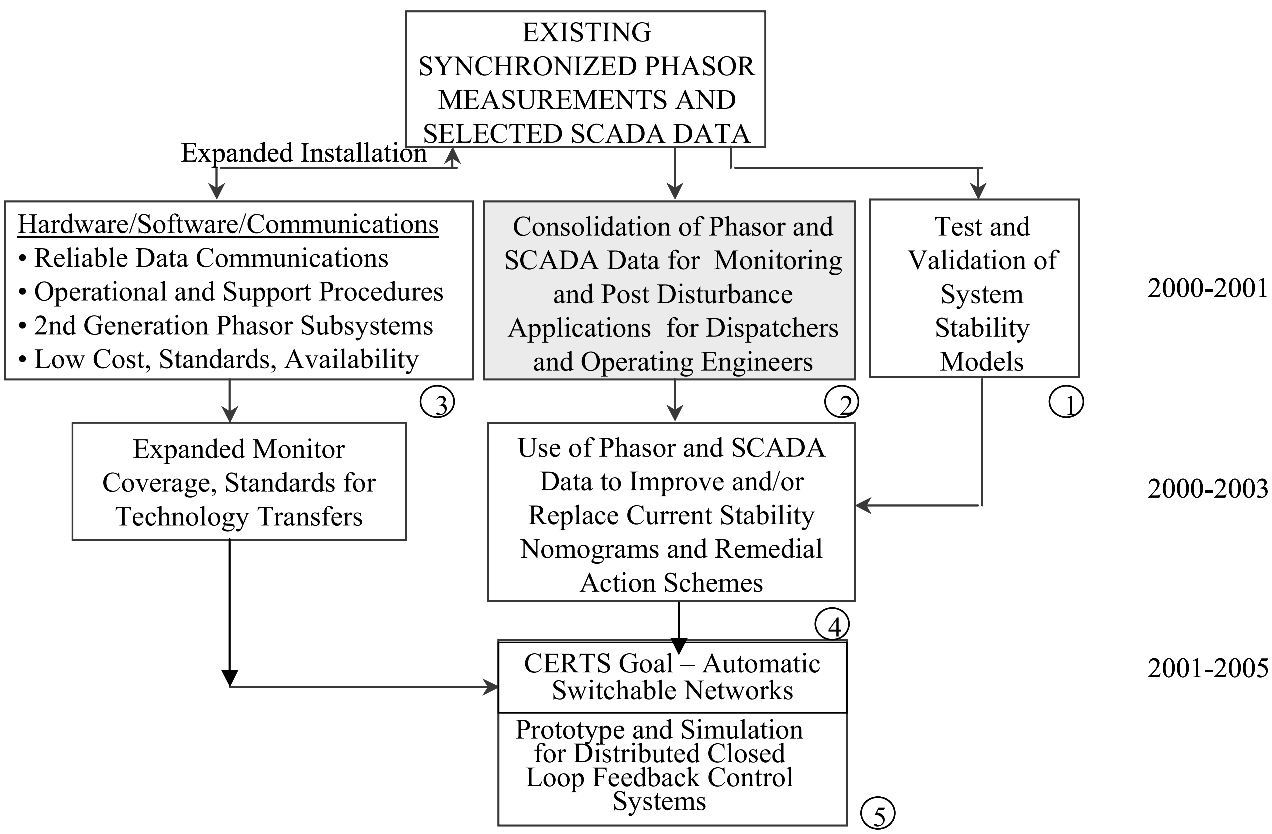
[1] PMU – Phasor Measurement Unit. "Intelligent" digital transducer designed to extract phasor quantities from point-on-wave voltage and current measurements.
[2] PDC – Phasor Data Concentrator. Collects data, controls, monitors and archives phasor measurements.

The third phase will use the experiences from the first two phases to research prototypes and demonstrate new real time distributed control schemes using synchronized phasor measurement technologies, see right side from Figure 1.

1.1 Effective Utilization of Phasor Measurement Technologies

During the first quarter of Year 2000, Stakeholders representing utilities, manufacturers and academia met at Berkeley, California, to review and discuss the current status and future directions for security monitoring and control applications using synchronized phasor measurement technologies. The major recommendations coming from this Stakeholders meeting were adopted by CERTS in the preparation of the research work plan as shown in Figure 2. The figure shows the major functional areas, ① to ⑤, where CERTS will be conducting research in during this multi-year project for the second phase of their research roadmap for Real Time Grid Reliability Management shown at center of Figure 1. Figure 2 also shows the interrelationships between each functional area and its corresponding development timeframe.

Figure 2 -CERTS Functional Areas for Utilization of Phasor Measurement Technologies



The following is a brief description for each of the targeted five functional areas:

- Functional area number ① – Through ongoing DOE Outreach activities, CERTS is participating in comprehensive assessment and validation of the stability models used in WSCC planning. This involves extensive direct tests of WSCC system behavior.
- Functional area number ②, shaded area in Figure 2, will be PC-based workstations for real time monitoring, system dynamic performance and post disturbance assessment using synchronized phasor measurements for the Dispatcher and Operating Engineering. These applications are the main focus of this functional specification and corresponding workstations.
- Functional area number ③ will create the necessary user and system support guides, manuals and standards for current Phasor Measurement infrastructures, and defines and evaluates alternatives to improve data communications and define second-generation phasor technology.
- Functional area number ④ will focus on enhancing the current deterministic stability nomograms and remedial actions schemes using synchronized phasor measurements. Some of the algorithms from this area will be used for the dispatcher applications in functional area ② during the next phase of this project.
- Functional area number ⑤ is CERTS ultimate goal for applications using phasors. It will take advantage of the experiences learned during functional areas ① to ④ to conduct the necessary research and prototyping of new real time distributed control schemes, which will lead the way to future automatic switchable power networks.

1.2 Environments Involved in the Utilization of Synchronized Phasor Measurements

Figure 3 Synchronized Phasor Measurements Environments

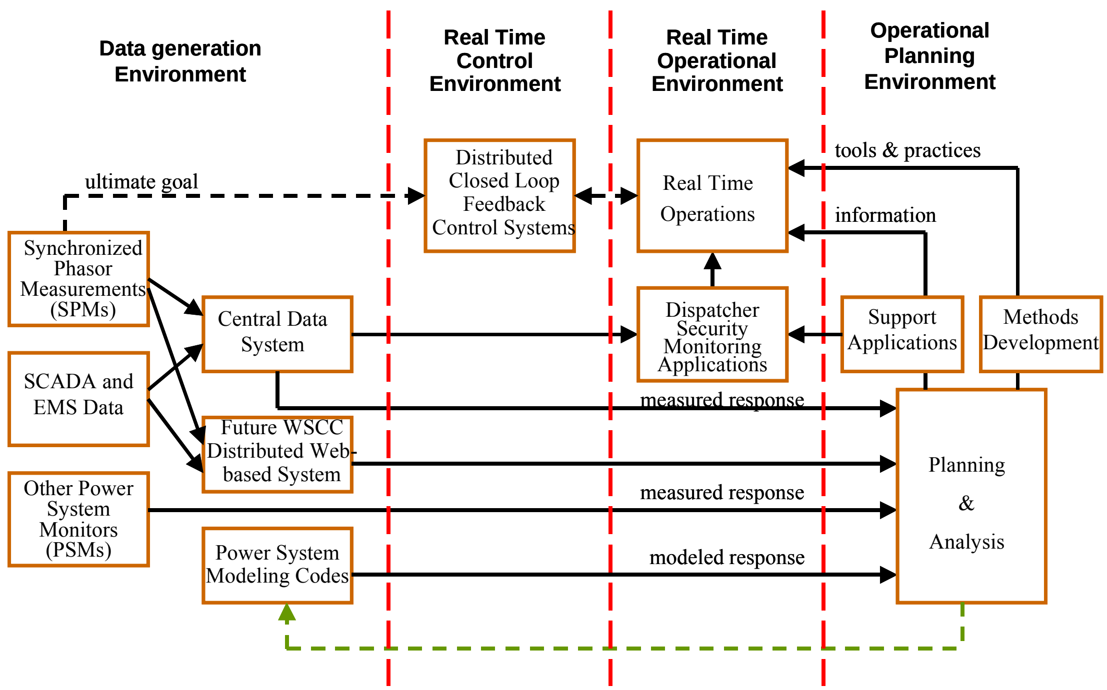


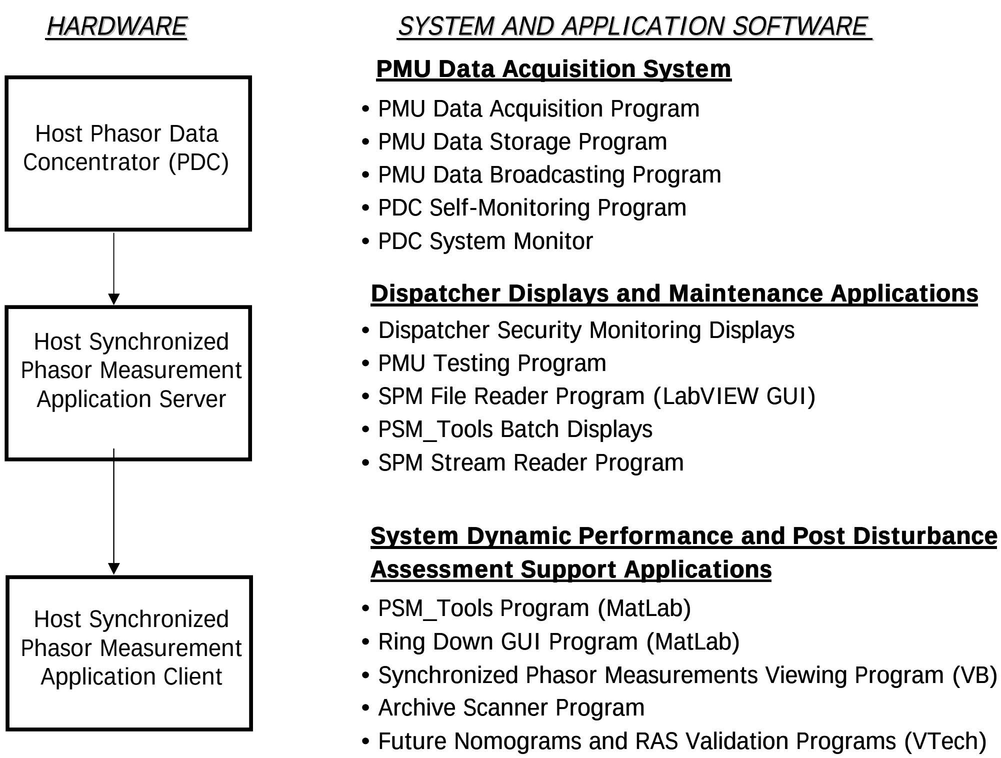
Figure 3 shows one overview of the four major environments involve for each of the areas where this technology will be applied: future automatic switching control, security monitoring, system dynamic performance and post disturbance assessment applications for dispatcher and operating engineering personnel. After SCADA and SPM data is acquired, there are three remaining utilization environments, one for automatic switching control, one for real time operations with Dispatchers oriented displays and security monitoring applications and a third one for Engineering Support Groups.

The dispatcher security monitoring displays and applications, system dynamic performance and post-disturbance applications to be prototyped for functional areas ② and ④ in Figure 2 will have similar functional characteristics as the ones developed by CERTS for their Reliability Adequacy Tools - VAR Management and Ancillary Services, with specific modes for performance, tracking and predictive conditions. The CERTS Adequacy Tools were developed during 1999 and are currently in their beta-phase testing at some operational sites. Their functional specifications are available from CERTS.

1.3 Hardware, System and Applications Software Overview

Figure 4 shows an overview of the hardware, system and application software configuration for the applications being developed for HOST.

Figure 4 – Architecture of Synchronized Phasor Information System



The architecture of this Synchronized Phasor Measurement System is made of the three computers shown at left side of Figure 4 and the system and application software to reside in each computer is software shown at the right side of Figure 4.

The security monitoring applications for Dispatchers and Operating Engineering using synchronized phasor measurements have been identified and divided into the following major functional categories:

1.3.1 Dispatcher Security Monitoring Displays

During phase-1 of the project the following security monitoring displays will allow dispatchers to monitor in real time any of the phasor data coming from the Phasor Data Concentrator (PDC) both at a phasor- level or at a system level. In addition, dispatchers will be able to identify the “stiffness” or sensitivities of certain predefined local and/or system critical parameters.

Figure 5

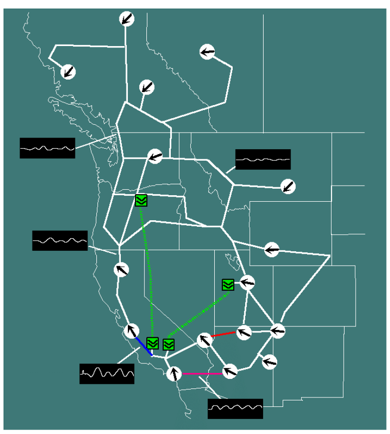


Figure 6

Figure 7

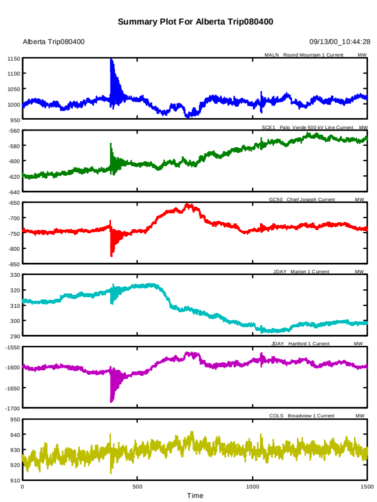
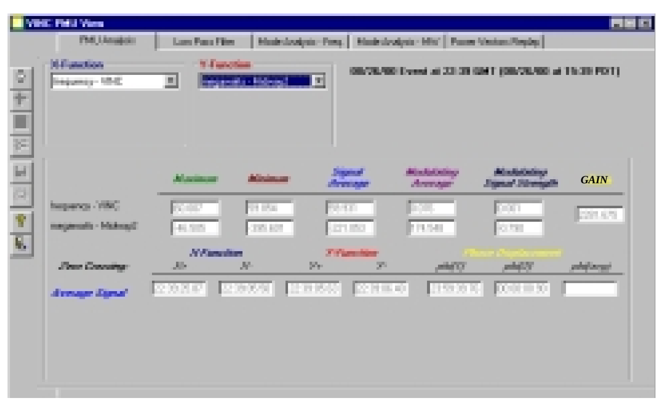


Figure 8



Following is a brief description for each display. Detail descriptions can be found in Section 7.2.2.

Figure 5-Via a graphic-geographic display dispatchers will monitor, in real time, relative bus angles as rotating vectors, colored line currents, and strip-charts for key predefined interconnections to monitor voltage and reactive reserves behaviors that currently they can not monitor with displays based only in SCADA data.

Figure 6 and Figure 7 are configurable displays that will allow dispatchers to use phasor data to monitor security at a system level. Key system parameters at key stations can be configured on the displays to monitor signal patterns that, via the engineering tools, have been defined, assessed and be predefined such Dispatchers can monitor that those parameters to check they do not violate specific thresholds predetermined by operating engineers.

Figure 8 is another configurable display that will allow dispatcher to monitor "gain" (stiffness) or sensitivities of predefined key system or local parameters checking they do not violate predefined sensitivity thresholds predetermined by operating engineers.

1.3.2 System Dynamic Performance and Post Disturbance Assessment Support Applications – The following applications will provide the operating engineering staff and support operating authority with the necessary tools to perform system dynamic performance and post disturbance analysis and assessments. In addition the engineering staff can identify disturbance data to archive for future disturbance signature recognition for the Dispatchers Security Monitoring Applications.

System Dynamic Performance and Post Disturbance Analysis Applications include the following programs:

- Power System Monitoring (PSM) Tools Program
- Ring Down Graphical User Interface (GUI) Program
- Synchronized Phasor Measurements Viewing Program
- Archive Scanner Program
- Future Nomograms and Remedial Action Scheme (RAS) Validation Program

These programs perform essential functions such as records integration, display, filtering, spectral analysis, hardcopy plotting, and saving of data into standardized file structures for later use. Processing logs are generated automatically, and summary logs are incorporated into all hardcopy or file results. These applications provide a single framework in which the user can view and process power system response records from any source for which an appropriate data translator is available. It also provides interfaces to more advanced elements of the Power System Identification (PSI) Toolbox, and to the many add-on toolsets for signal analysis, controller design, and other advanced tasks. A SPM Viewing Program will calculate and show to dispatchers the gain (stiffness) of certain predefined system parameters. The future Nomograms and Remedial Action Schemes (RAS) programs will violate and complement current Nomograms and RAS schemes using Synchronized Phasor Measurements.

1.3.3 Future Dispatcher Displays and Security Monitoring Applications (2001-2002)

During phase-2 the following applications will provide operating authorities with a set of tools to effectively monitor the security or reliability of the grid. The three major future dispatcher performance monitoring applications using SPM will be:

- Stability Dynamic Loading Monitoring (application will complement the current static stability nomograms) - Currently, the Dispatcher or an EMS program takes actual line or path loadings and plots it on a static stability nomogram to determine if the system is operating within limits, based on prior studies. The performance monitoring application, using real time SPM data, will compare the phase angle between critical busses to validate if the system is actually operating within limits or advise the Dispatcher that limits are being exceeded. The application will also serve to validate the nomograms. Over time and after gaining confidence with this application the static nomogram potentially could be replaced and transfer capability decisions could be made based on the information received from the SPM's.
- Remedial Action Schemes (RAS) Monitoring - Currently, remedial action schemes are designed to operate based on input from the status of the circuit breaker(s) associated with the lines or path. The assumption is that based on off line studies there is a high probability that the system becomes unstable after the loss of a critical transmission element. The performance monitoring application, using real time SPM data, will compare the phase angle between the critical busses, during or after the loss of a transmission line, to determine if in reality the system would have become unstable and also will be used for RAS validation purposes.
- Preventive Disturbance Monitoring - Dispatcher monitors near real time instability predictions calculated using SPM data. This would provide the dispatcher with advanced warning of potential unsafe conditions and allow them to define and execute the necessary preventive operational actions.

1.3.4 Future SPM Support Applications (2001 – 2003)

During phase-2 the following support applications will be deployed:

- Area State Estimation. Using the current set of WSCC Synchronized Phasor Measurements, area state vectors will be calculated for those regions of the WSCC where currently enough phasor measurements are available. The goal is to provide the security coordinators with critical wide-area system monitoring data that is more accurate and reliable that is currently produced by software-base wide-area state estimators.
- Load Modeling. To be defined by Reviewers
- Event Recording (Disturbance Signature) – Develop a database of disturbance signatures that will support further research and development of phasor measurements based applications and grid automation.
- Fault Identification Analysis.

1.3.5 Overview of the SPM Applications Specification

The remaining sections of this specification will cover the following areas – Section 2 describes the initial end users targeted for the dispatcher security monitoring applications. Section 3 compares data performance and data availability characteristics between SCADA and SPM systems and graphically shows where and how many PMUs and PDCs have been deployed within the nation major interconnections. Section 4 also graphically shows where data transfer of phasor data have been implemented with Section 5 showing current typical local configurations to disseminate phasor data to end users. Section 6 summarizes the different dispatcher security monitoring applications with its corresponding functional, data, visualization and performance requirements and characteristics. Section 7 describes the characteristics for the HOST hardware and application software deliverables. The last section, Section 8 includes CERTS hierarchical data visualization methodology that will be used to define the displays for HOST dispatchers, and shows samples for some of the current user's phasor displays at BPA and SCE. Section 9 is an overview of the HOST resources required and the training and documentation needed. Attachment A is a sample of the process and corresponding displays required to do post disturbance assessment. An August 26, 2000 disturbance was selected for that purpose. Attachment B is a copy of the WSCC Plan for Dynamic Performance and Disturbance Monitored submitted on September 15 for approval by the WSCC Operating Committee.

1.3.6 Main SPM Applications Goal

The main goal for each of the dispatcher and Operating Engineering security monitoring applications described in this specification is to research, develop and demonstrate an assortment of dispatcher monitoring tools, system dynamic performance and post disturbance assessment applications that use synchronized phasor measurement data, graphic-geographic visualization elements and will provide more accurate, reliable and effective real time assessment of the grid reliability within the nation inter-connections.

Theoretically, other techniques using data sets, such as SCADA data, could serve some of the proposed applications adequately. However, from a practical perspective SPM's very fast characteristics, improved accuracy and particularly its wide-area synchronization, make these measurements the most suitable for these dispatcher security-monitoring applications.

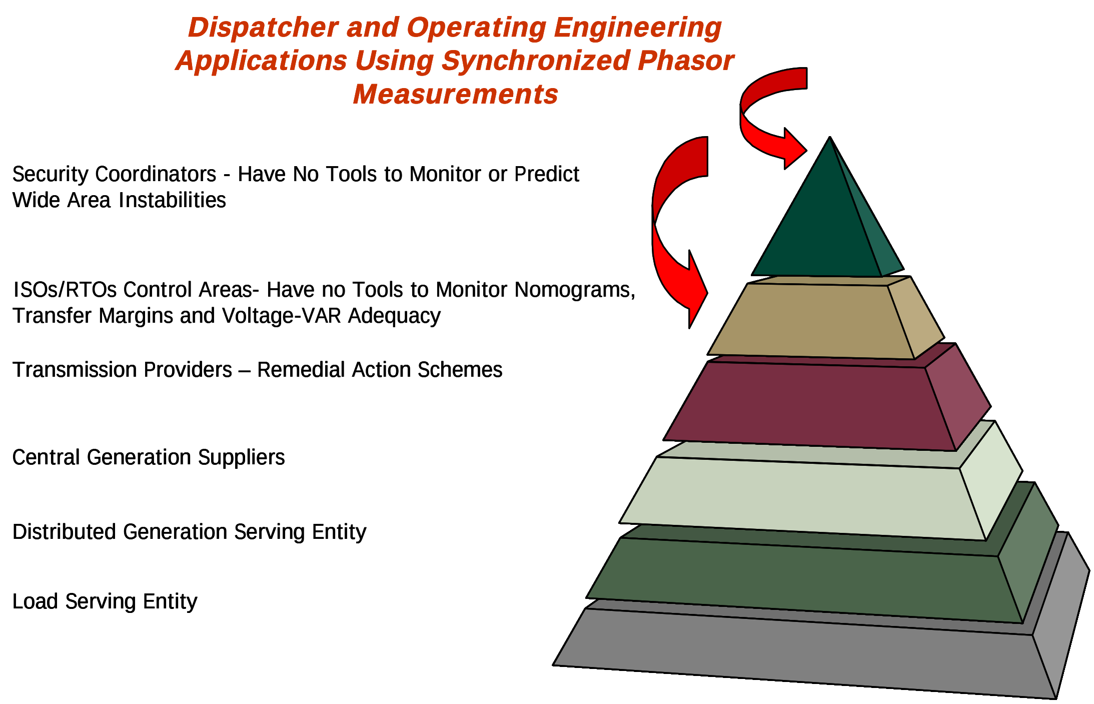
The development and ultimate deployment of these stability-monitoring applications will enhance the operating authorities ability to manage larger and more complex grids operating within deregulated competitive market environments. In addition, deployment and operational experiences gained with these applications will prove valuable during future research into the real time distributed controller requirements for automatic switchable networks.

2. TARGET USERS FOR SECURITY MONITORING, SYSTEM DYNAMIC PERFORMANCE AND POST-DISTURBANCE APPLICATIONS

Industry stakeholders are recognizing new jurisdiction levels for system reliability and operational control within emergent market environments that follow a hierarchical structure with new jurisdictional operational levels that did not exist before.

Figure 9 shows the traditional and new NERC proposed hierarchical control levels for power system reliability and control management. Some of the new proposed jurisdictional levels such as Security Coordinators and ISOs are already being implemented in some regions of the country.

Figure 9 – Target Users for Applications of Synchronized Phasor Measurements



The functional requirements for SPM applications will depend on which operational level and control approach is being addressed, such as the traditional central approach or new distributed approaches. The functionality identified and described on this specification has been oriented towards the distributed control and monitoring environments, with the operating authority following the hierarchical control levels shown in Figure 9.

Within the operating authority organizations the SPM security applications have been targeted for security monitoring dispatchers with specific monitoring displays initially, and specific applications and displays for complementing current stability Nomograms and remedial action schemes (RAS) in phase-2. The second users targeted are operating engineers with system dynamic performance and post disturbance assessment tools.

3. PHASOR MEASUREMENTS PERFORMANCE AND AVAILABILITY - CURRENT INSTALLATIONS

The following subsections describe the special characteristics of SPM data and compare those characteristics with its equivalents for SCADA data. The subsections look into SPM characteristics, comparisons between SPM and equivalent SCADA data, geographical locations for current SPM infrastructures, current inter phasor data interconnections, and finally a description of two typical local architectural configurations deployed at BPA and SCE to deliver SPM data to their end users.

3.1 Performance and Availability Characteristics - Comparison Between SCADA and Synchronized Phasor Measurements (SPM)

Table 1 shows the differences between performance characteristics for SCADA data and corresponding performance for Synchronized Phasor Measurements (SPM). Six major data characteristics are contrasted: data speed, data accuracy, data synchronization, bandwidth, latency and measurement set. CERTS has establish under research area-2 from Figure 2, a special project with Sandia leading the effort to identify bandwidth and latency requirements and to research and recommend network architecture that satisfy those requirements.

Table 1 – Data Characteristics Comparison between SCADA and SPM

Main Characteristics	SCADA-EMS	Synchronized Phasor Measurement
Speed	SCADA are usually 10-40 cycles long and are collected every 1-4 seconds	SPM are 1 cycle long and can be easily collected every 1-4 cycles.
Accuracy	0.5% to 1%	0.5% to 1%
Synchronization	SCADA are only synchronized to the degree of the scan rate. Usually there is not data synchronization between different SCADAs.	SPM are synchronized within 0.1 electrical degree (5 microseconds) and can be accurately compared system wide
Bandwidth	Not major limitations	CERTS / Sandia Investigating
Latency	seconds	CERTS / Sandia Investigating
Measurement Set	SCADA must provide transducer and reading for each measurement.	SPM provides raw voltage and current (magnitude and angle) from which power, magnitudes and angles, are easily derived.

Note: Characteristics are under revision by CERTS / Sandia

Table-2 identifies data type differences between SCADA and SPM measurement systems. From Table-2, three major differences can be observed: data sampling periodicity, a new measurement - phasor angles - not existing in the SCADA, and three measurements that in SCADA systems are not actual but computer calculated. As it will be noticed in the next sections, these unique phasor measurement characteristics together with the ones shown in Table-1, will allow the calculation of new more accurate system performance parameters that will be the basis for new and complementary security monitoring applications widening the monitoring window for dispatchers.

Table 2 – Data Types Comparison between SCADA and SPM

Type	System Measurement	
	SCADA-EMS (4 seconds)	**Phasor Data (1/30 seconds)**
Frequency and Frequency Deviation	Available	Available
Voltage Magnitude	Available	Available
Voltage Angle	Not Available	Available
Currents Magnitude	Available	Available
Currents Angle	Not Available	Available
Positive sequence phasors	Calculated	Actual
Negative sequence phasors	Calculated	Actual
MW and MVAR	Calculated	Actual

3.2 Regions with Synchronized Phasor Measurement Installations

During the last 10 years, PMUs and PDCs have been installed in different regions of the three major North American Interconnections as shown in Figure 10.

Table-3 and Figure 10 also show in which States and the specific Utilities where SPM's have being installed, and how many PMUs, PDCs and the number of phasor measurements points that are currently available. Two observations can be made from Figure 10, first, only in the Western Interconnection is synchronized phasor data being interchange between different operating regions, and second, PMU clusters are being located in those geographical areas where currently major power transfers take place.

Table 3 – PMUs Installed in WSCC and Eastern Interconnection

PMUs installed in					
WSCC	**PMUs**	**Estimated Phasor Measurements**	**Eastern Interconnection**	**PMUs**	**Estimated Phasor Measurements**
BPA	8	50	AEP	4	20
APS	3	5	TVA	4	20
SRP	2	5	NY	6	30
PG&E	3	5	GEORGIA	1	5
LDWP	3	5	FLORIDA	2	5
WAPA	2	10			
SCE	9	53			
BC Hydro	3	18			
Total WSCC	33	151	Total Eastern Interconnection	17	80

Note: PG&E has 4 PMUs, 3 installed, none operating; LDWP has 3 PMUs, 1 operating

Figure 10 – Interconnections with Synchronized Phasor Measurement Installations

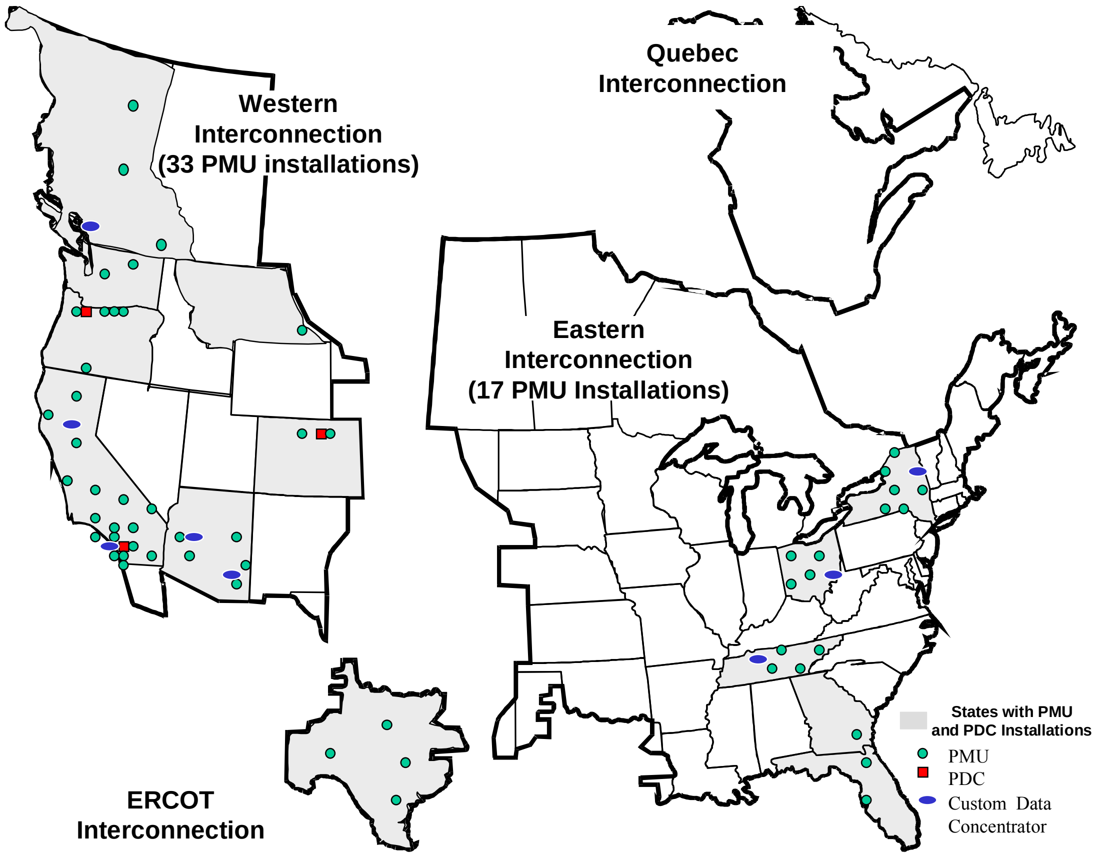


Table-4 shows, for each region, the number of synchronized phasor measurements by station and voltage.

Table 4 – Current Synchronized Phasor Data Availability

Phasors installed in WSCC	Phasors
SCE	
St-1 500 kV and 230 kV busses	5
St-2 230 kV bus	5
St-3 500 kV and 230 kV busses	8
St-4 230 kV bus	10
St-5 500 kV bus	5
St-6 230 kV	5
St-7 230 kV bus	5
St-8 115 kV bus (for load analysis)	5
St-9 66 kV bus	5
BPA (PDC exchange from BPA)	-
Total SCE	53
BPA	
St-1 500 kV bus	5
St-2 500 kV bus	10
St-3 500 kV	5
St-4 500 kV bus	5
St-5 230 kV bus	10
St-6 500 kV	5
St-7 230 kV bus	5
St-8 500 kV and 230 kV buses	5
SCE (PDC exchange from SCE)	4
Total BPA	50
PG&E	
St1 500kV bus	5
St2	
Total PG&E	5
LDWP	
St-1 220 kV bus	5
Total LDWP	5
CAISO	
None	0
Total CAISO	0
WAPA	
St-1 345 kV bus	5
St-2 345 kV and 230 kV buses	5
Total WAPA	10
APS	
St1	5
St2	
Total APS	5
SRP	
St1	5
St2	
Total SRP	5
BC Hydro	
St-1 500 kV bus	5
St-2 500 kV bus	5
St-3 500 kV bus	8
Total BC	18
Total WSCC (estimated)	151

Phasors installed in Eastern Interc.	Phasors
AEP	
St-1	TBD
Total AEP (estimated)	20
TVA	
St-1	TBD
Total TVA	20
NY	
St-1	TBD
Total NY	30
GEORGIA	
St-1	TBD
Total GEORGIA	5
FLORIDA	
St-1	TBD
Total FLORIDA	5
Total Eastern Interconnect. (estimated)	80

Figure 11 Shows in detail where, in the WSCC interconnection, PMUs and PDCs have been deployed and how they are interconnected. It should be noticed that PMU clusters have been deployed already at the extremes of the WSCC north-south and east-west power corridors. However, it is still unknown if the number of PMUs in these different clusters will be enough for the requirements of the dispatcher applications identified in this specification. One of the initial main tasks is to identify the minimum set of PMUs required to satisfy the accuracy required for real time monitoring and the range of accuracies achievable with existing phasor data. Another observation is that there is not standardization neither for PMU and PDC data transfer protocols. The protocols currently in use are proprietary and tailor-made.

Figure 11 - WSCC PMU and PDC Location and Connectivity

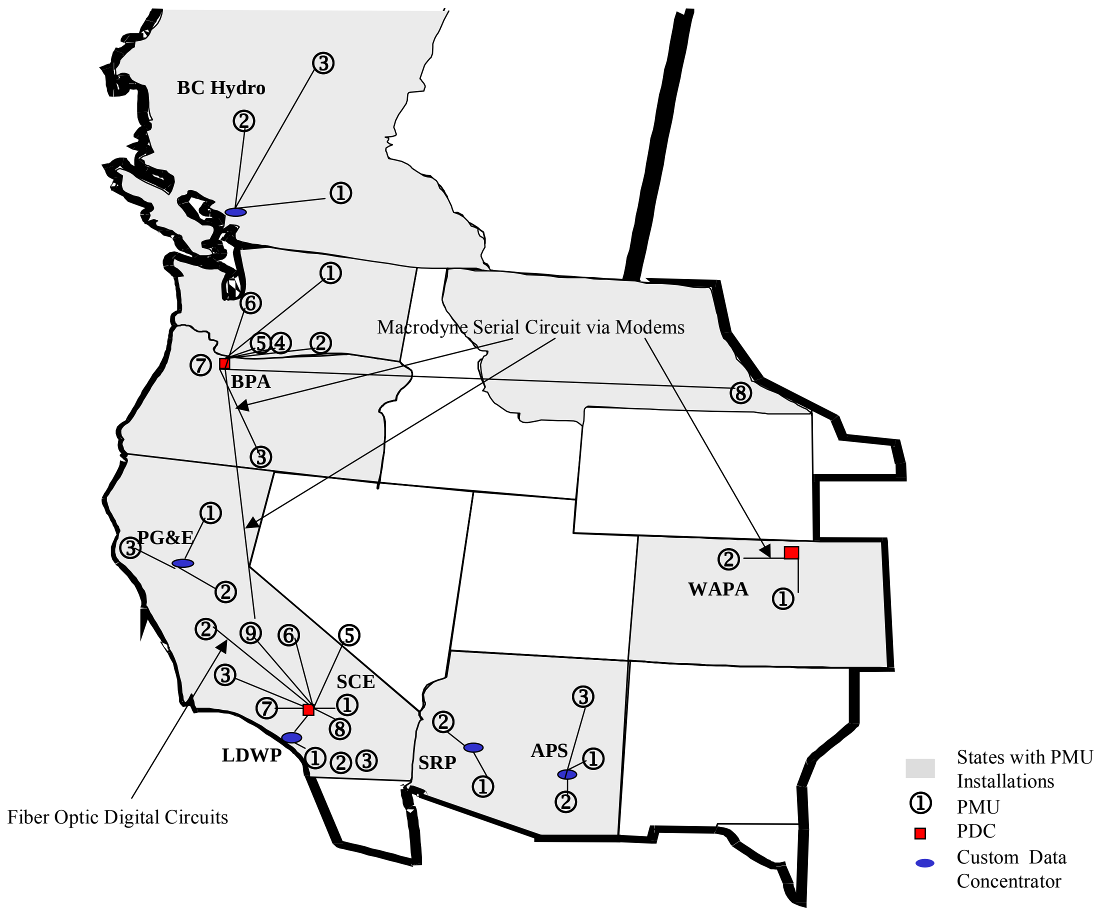
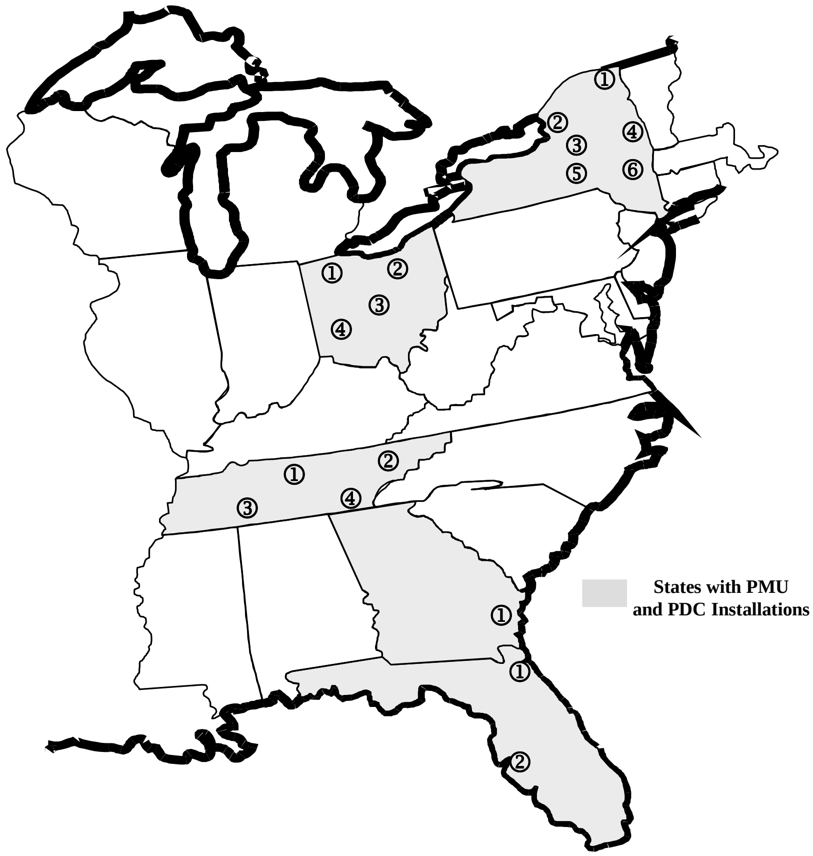


Figure 12 shows where in the Eastern interconnection PMUs have been deployed. It is unknown if the number of PMUs in this different clusters will be enough for the requirements of the dispatcher applications from this specification. One of the initial main tasks is to identify the minimum set of PMUs required to satisfy the accuracy required for real time monitoring and for the system dynamic performance and post disturbance assessment applications.

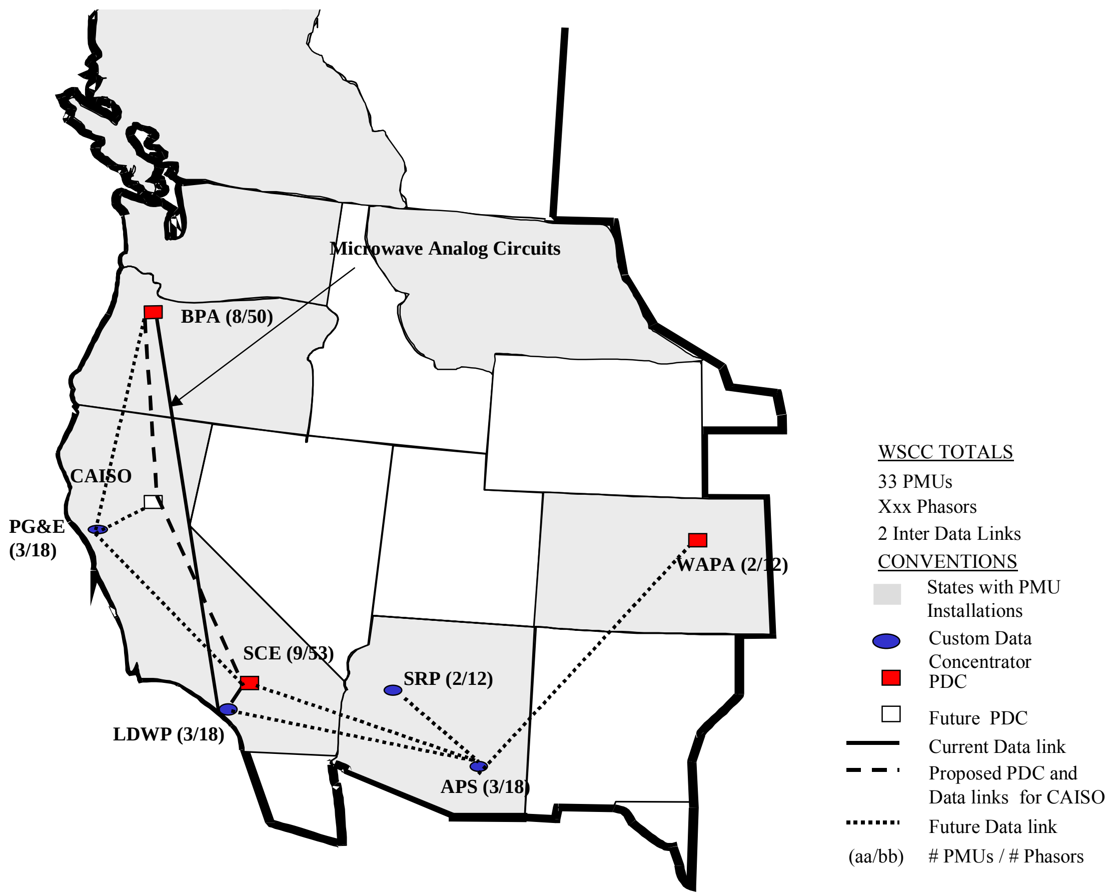
Figure 12 - East Coast PMU and PDC Location / Connectivity



4. CURRENT AND FUTURE WSCC SYNCHRONIZED PHASOR MEASUREMENT NETWORK FOR A TYPICAL ISO

Figure 13 shows a synchronized data communication network proposed to feed data to the Dispatchers Security Monitoring, System Dynamic Performance and Post Disturbance assessment applications. The figure shows three types of phasor data links, one continuous line for current links, discontinuous lines for the two proposed data links for a CAISO workstation, and dotted lines for future phasor data links.

Figure 13 – Current and Future WSCC Phasor Data Communication Network



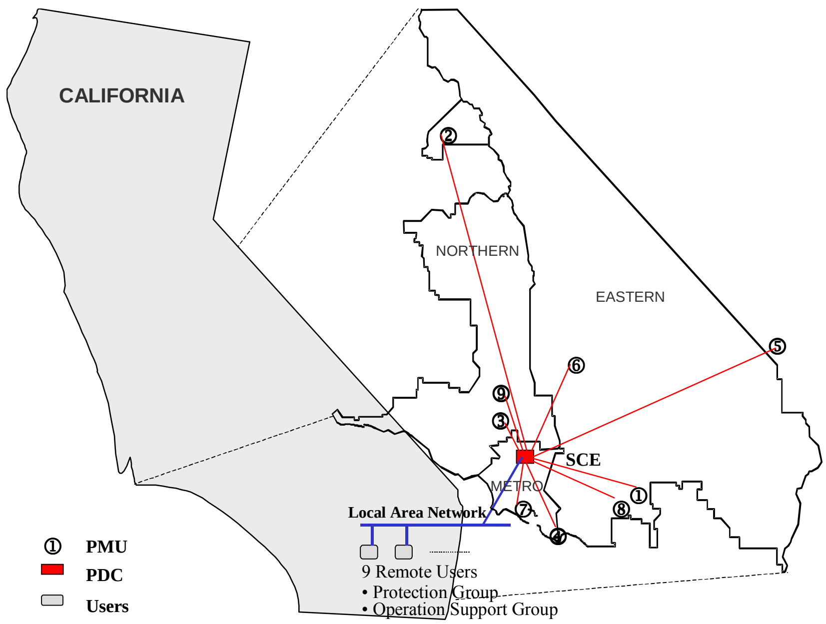
The current WSCC phasor data link consists of an analog microwave portion between BPA in Vancouver, WA and LDWP headquarters in Los Angeles and a digital link from there to SCE in Rosemead. The connection uses a pair of 33.6 KBPS analog modems and interfaces directly to the analog microwave in Vancouver. BPA and LDWP analog microwave systems connect in Southern Oregon. At LDWP headquarters, the signal is received and translated from the analog microwave to a digital format on the LDWP digital microwave transmitter. It is then sent to Mt. Lukens in the San Gabriel Mountains. There it cross connects to SCE digital fiber optics and travels to the PDC at SCE Headquarters in Rosemead, California where a standard interface converts the signal back to analog for users distribution.

The additional phasor data links will connect the new CAISO PDC with the PDC's from BPA and SCE using similar characteristics as the current BPA-SCE phasor data link.

5. TYPICAL PMU-PDC LOCAL CONFIGURATIONS INTERFACED WITH END USERS LOCAL AREA NETWORKS (BPA and SCE)

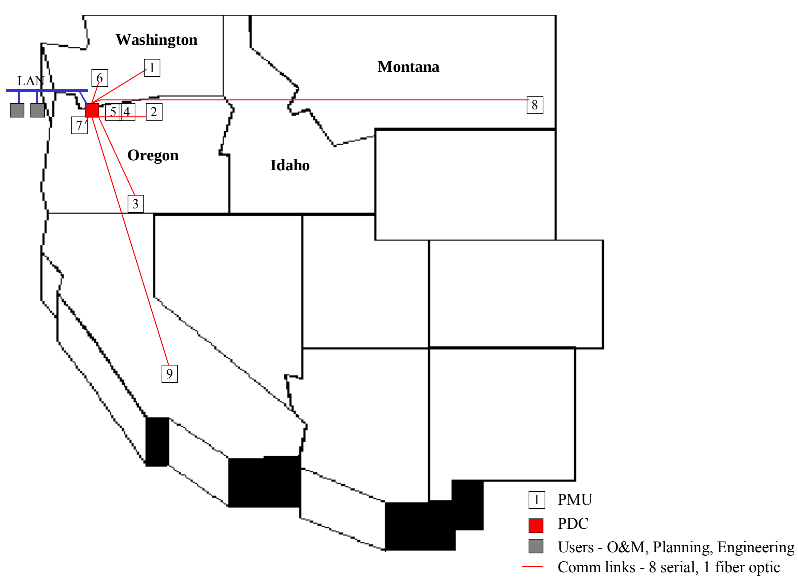
Figure 14 shows, for reference purposes, the current PMU - PDC configuration and data paths for Southern California Edison end users. It also shows their fiber optic links where it is pertinent.

Figure 14 – Synchronized Phasor Measurement Network for SCE



In analog way to SCE, BPA has a network of Phasor Measurement Units (PMU) and Phasor Data Concentrator (PDC) interfaced with their end users as shown in Figure 15.

Figure 15 – Synchronized Phasor Measurement Network for BPA



6. SECURITY MONITORING AND POST DISTURBANCE APPLICATIONS USING SYNCHRONIZED PHASOR MEASUREMENTS (SPM)

The Security monitoring applications for Dispatchers and Operating Engineers using Synchronized Phasor Measurements (SPM) have been categorized in the following four major areas:

6.1 Dispatcher Security Monitoring Displays

Real-time SPM data can be viewed with the Stream Reader and with various Security Monitoring Displays. Archived data can be viewed with several other tools, in a variety of ways. Examples of these displays are shown in Figures 16 through Following are some of the displays for dispatchers (see corresponding figures in Section 7.2.2):

Figure 21 provides a visual overview of wide-area dynamic response in the WSCC's interconnected system. Relative bus angles are shown as rotating vectors, line currents are mapped to various colors, and strip charts show power across key interchanges. Equivalent display will be created using SCADA and SPM measurements.

Figure 22 shows plots of data from a file recorded by a PDC scaled to engineering units stored in a configuration file. The graphical display has 4 time-correlated plots, each of which will support multiple traces. This allows comparing many parameters for determination of signal interactions. The plots may be printed with a complete legend and title.

Figure 23 shows PDC data plots produced by one of the display options in PSM_Tools. The traces represent five PDC files joined together, and are accompanied by automatic documentation as to the source data and the processing used (e.g., bandpass filtering). Displays of this kind are commanded by means of preset menus indicating the signals of interest and the processing to be done.

Figure 24 shows the Synchronized Phasor Measurement Viewing Program capability to calculate the gain (stiffness) (MWs/per Hz) for the Midway-2 line to help in the post disturbance assessment. This screen can be used to calculate the changes of load, generation with respect to frequency or MVAR with respect to voltage for the disturbance file. Equivalent displays will be design to calculate parameters sensitivities in the near future.

6.2 Operating Engineering Applications for System Dynamic Performance and Post Disturbance Assessment

The following applications will provide the operating engineering staff with the necessary tools to perform post disturbance analysis and assessments. In addition the engineering staff can identify disturbance data to archive for future disturbance signature recognition for the Security Operation Applications.

System Dynamic Performance and Post Disturbance Analysis Applications include the following programs (described in Section 7):

- PSMTools Program
- Ring Down Graphical User Interface (GUI) Program
- Synchronized Phasor Measurements Viewing Program
- Archive Scanner Program
- Future Nomograms and Remedial Action Scheme (RAS) Validation Program

These programs perform essential functions such as records integration, display, filtering, spectral analysis, hardcopy plotting, and saving of data into standardized file structures for later use. Processing logs are generated automatically, and summary logs are incorporated into all hardcopy or file results. This application provides a single framework in which the user can view and process power system response records from any source for which an appropriate data translator is available. It also provides interfaces to more advanced elements of the PSI Toolbox, and to the many add-on toolsets for signal analysis, controller design, and other advanced tasks.

Figure 16 shows the off-line information flow to assure system dynamic performance. The accuracy of the planning process requires balanced use of both measurements based and model based information. Planning models are essential for interpreting observed system behavior, and for predicting future behavior under assumed conditions. Continual refinement of models and practices is essential to a robust planning process and, ultimately, to overall power system reliability.

Figure 16 – Information Flow Overview to Assure System Dynamic Performance

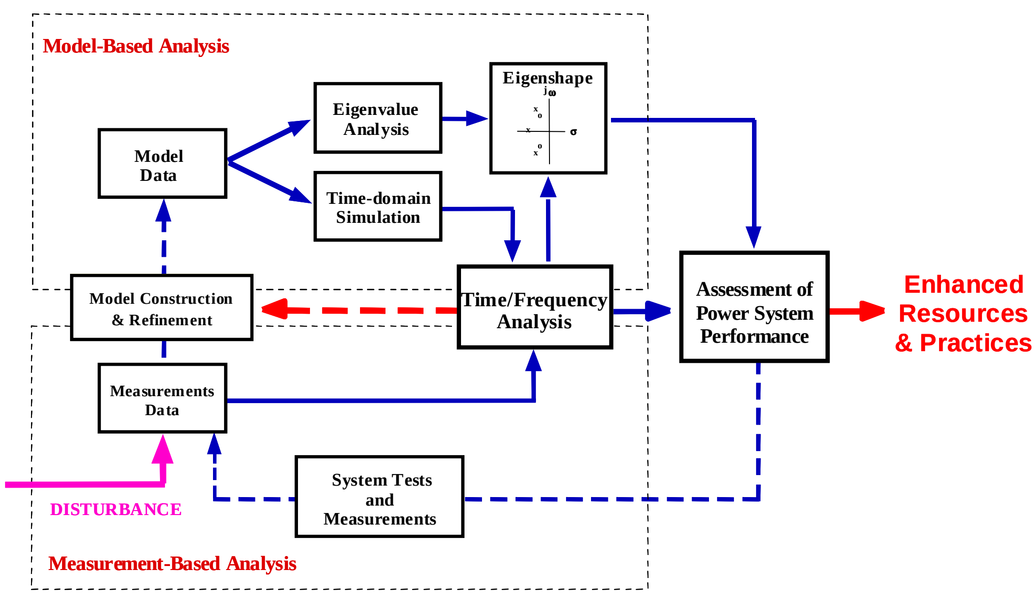


Figure 17 – Architecture for Advanced Dynamic Performance Monitor

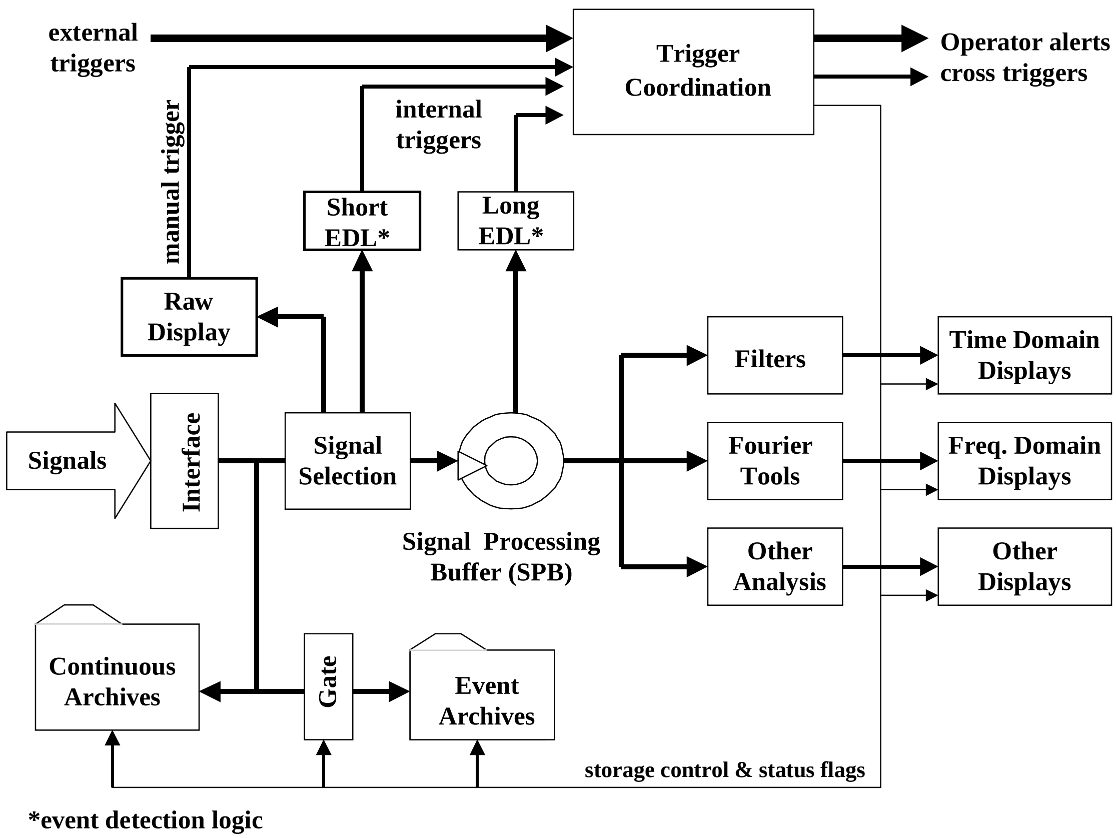


Figure 17 shows a configuration that is representative for a mature interactions monitor that is operating in a manned substation or in a system control center. Absence of an indicated perimeter for the monitor reflects the fact that this might well be a locally networked facility, containing several computers or other intelligent electronic devices (IED's) plus linkages to the energy management system (EMS).

The indicated triggers are both external and internal, manual and automatic. The internal automatic triggers are classified as short or long (fast or slow), depending upon length of the data segment needed by the associated event detection logic. Short EDL can work with a short block of recent data, and is manually sufficient for disturbance monitoring

A distinguishing feature in this architecture is the signal-processing buffer (SPB) used for advanced trigger (in the long EDL) and in special displays. SPB functionality is essential for extracting interaction signatures, and for presenting those signatures to operations staff for their interpretation and review. At hardware level, however, this functionality can be distributed among one or more buffers internal to the monitor itself plus external buffers for shared access to the record stream at file level.

6.3 Future Dispatcher Security Monitoring Applications (2001–2002)

During phase-2 the following applications will provide operating authorities with a set of tools to effectively monitor the security or reliability of the grid. The three major dispatcher performance monitoring applications using SPM will be:

- Stability Dynamic Loading Monitoring (application will complement the current static stability nomograms) - Currently, the Dispatcher or an EMS program takes actual line or path loadings and plots it on a static stability nomogram to determine if the system is operating within limits, based on prior studies. The performance monitoring application, using real time SPM data, will compare the phase angle between critical busses to validate if the system is actually operating within limits or advise the Dispatcher that limits are being exceeded. The application will also serve to validate the nomograms. Over time and after gaining confidence with this application the static nomogram potentially could be replaced and transfer capability decisions could be made based on the information received from the SPM's.
- Remedial Action Schemes (RAS) Monitoring - Currently, remedial action schemes are designed to operate based on input from the status of the circuit breaker(s) associated with the lines or path. The assumption is that based on off line studies there is a high probability that the system becomes unstable after the loss of a critical transmission element. The performance monitoring application, using real time SPM data, will compare the phase angle between the critical busses, during or after the loss of a transmission line, to determine if in reality the system would have become unstable and also will be used for RAS validation purposes.
- Preventive Disturbance Monitoring - Dispatcher monitors near real time instability predictions calculated using SPM data. This would provide the dispatcher with advanced warning of potential unsafe conditions and allow them to define and execute the necessary preventive operational actions.

6.4 Future Operating Engineer System Dynamic Performance Applications (2001 – 2003)

During phase-2 the following support applications will be deployed:

- Area State Estimation. Using the current set of WSCC Synchronized Phasor Measurements, area state vectors will be calculated for those regions of the WSCC where currently enough phasor measurements are available. The goal is to provide the security coordinators critical wide-area system monitoring data that is more accurate and reliable than the software-base wide-area state estimators.
- Load Modeling. To be defined by Reviewers
- Event Recording (Disturbance Signature) - Develop a database of disturbance signatures to use for further development of phasor measurements based applications and grid automation.
- Fault Location Analysis.

6.5 Main Advantages for Using SPM for Security Monitoring Applications

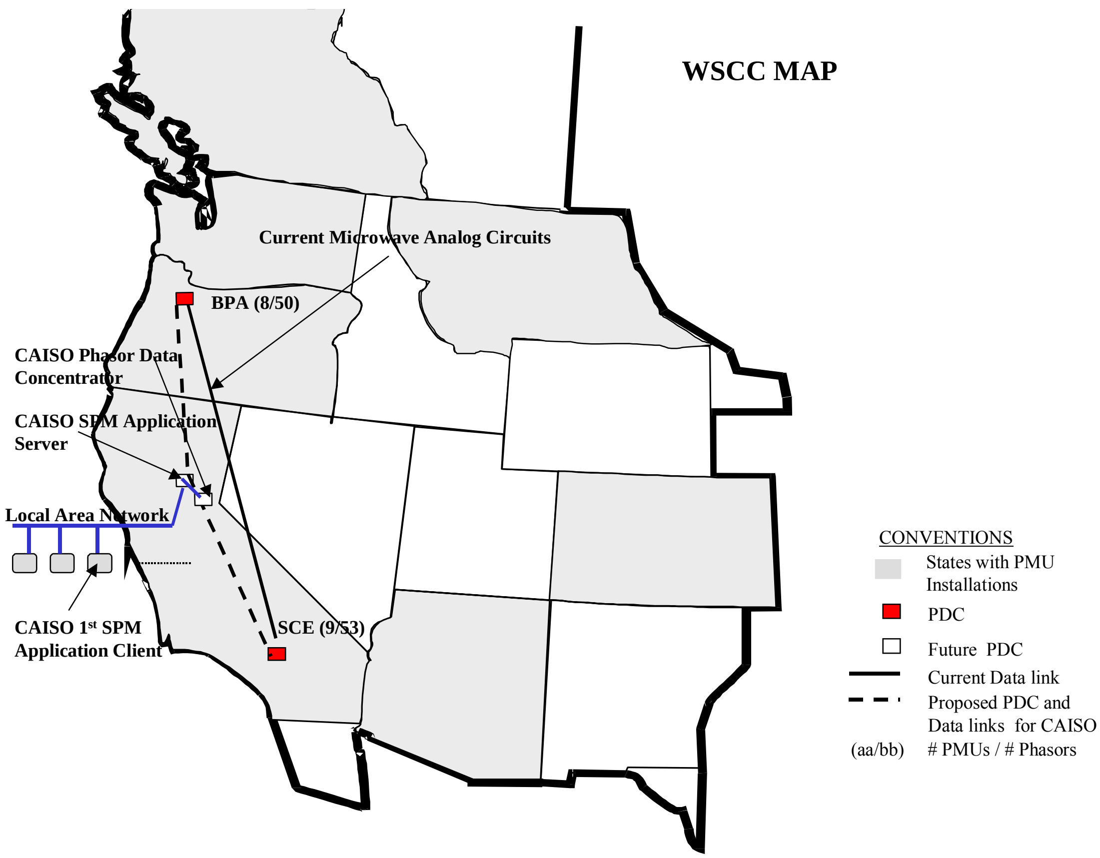
Theoretically, other techniques using data, such as SCADA data, could serve some of the proposed applications adequately. However, from a practical perspective SPM very fast characteristic, its improved accuracy and particularly its wide-area synchronization, make these measurements the most suitable set for the dispatcher security monitoring applications specified here.

The development and ultimate deployment of these stability-monitoring applications will enhance the operating authorities ability to manage larger and more complex grids. In addition, deployment and operational experiences gained with these applications will prove valuable during future research into the real time distributed controller requirements for automatic switchable networks.

7. HOST HARDWARE, DATA COMMUNICATIONS AND APPLICATION SOFTWARE FOR SECURITY MONITORING, SYSTEM DYNAMIC PERFORMANCE AND POST DISTURBANCE APPLICATIONS USING SYNCRONIZED PHASOR MEASUREMENTS

Figures 18 and 19 show an overview of the typical computer hardware and data communication infrastructures for the HOST to acquire and utilize subsets of the synchronized phasor measurements currently available from BPA and SCE. Figure 19 specifically, and in detail, shows the corresponding computer hardware architecture for this typical application with its proposed PDC, SPM application server and SPM engineering support user client.

Figure 18 – Overview of a Typical Hardware and Communications Configuration

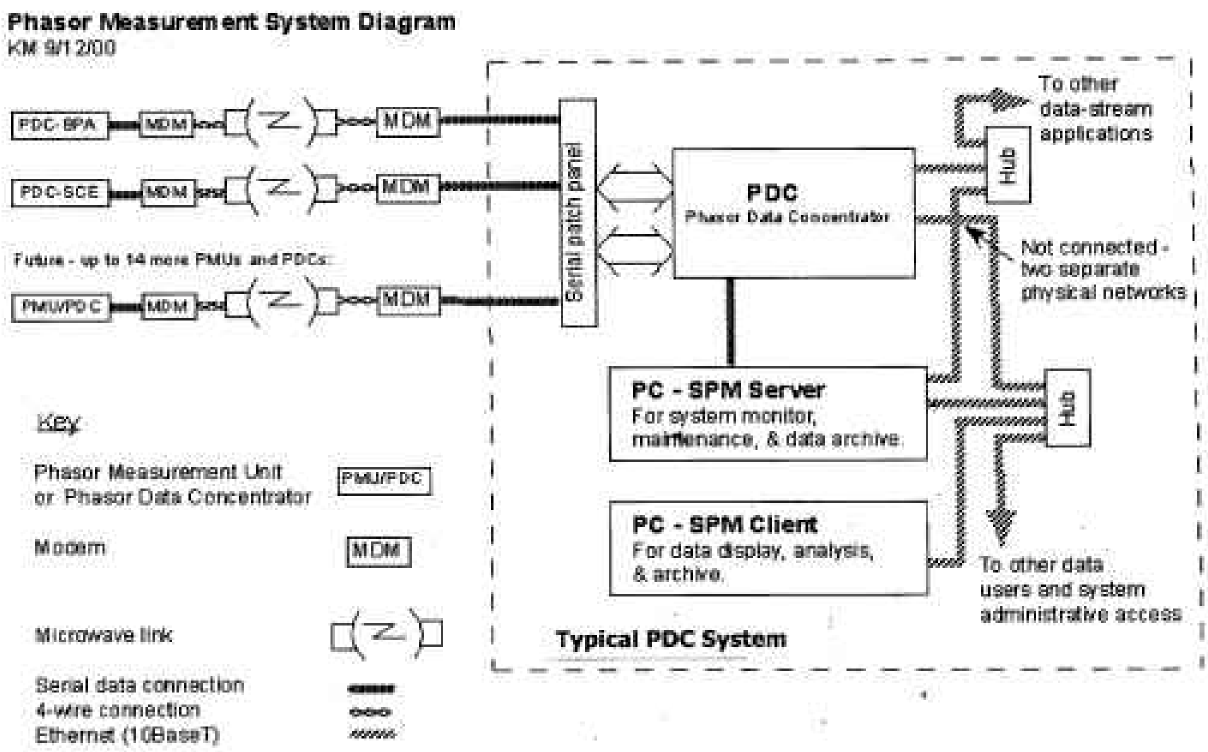


7.1 Phasor Data Concentrator (PDC) – See Figure 19

7.1.1 Typical PDC Hardware and Data Communications Descriptions

Typical PDC - This PDC will be equivalent to the Phasor Data Concentrator (PDC) as is being used at the Bonneville Power Administration (BPA) and Southern California Edison (SCE), and it will be configured as shown in Figure 19. It will be specifically configured to input data from the PDC units at SCE and BPA using the established data exchange protocol, but have all the standard features that allow direct PMU input as well for the future. The important PDC features include:

Figure 19 – Typical Hardware and Communications Configurations Overview



- Capability for 16 serial inputs from PMUs or other PDCs
- Capability for output to other PDCs
- Continuous data output over Ethernet
- Two Ethernet ports for connectivity on separate networks
- 18 GB of data storage on hard disc (will hold approximately 7200 disturbance events)
- Complete system manual

The PDC is designed to input phasor measurement data from many measurement units in real time. It correlates the data from multiple sources by time stamp and provides data outputs, disturbance recording, and system monitoring. The principle PDC functions are:

- Input data by serial communications from up to 16 PMUs or other PDC units
- Output data to other PDC units over the same input links
- Broadcast the complete correlated data set in real time over Ethernet using the IP protocol for use by multiple applications
- Communicate phasor information to a SCADA system. This is being used at BPA, but due to proprietary protocols commonly used in SCADA systems, this would require modifications to be used elsewhere.

- Record data files during system disturbances. When a PMU detects a disturbance, it sets a bit in the real-time data stream. This bit is detected by the PDC, which then records a 3-minute file, including 55 seconds of pre-disturbance data. It will record continuing files for the duration of the disturbance.
- Display system status by serial or network link to a PC hosted system monitor that displays the current system status and operational records.
- Easy configuration with text files. Most configuration changes only require editing a text file and re-booting the PDC. Step-by-step instructions for all procedures are provided in the manual.

The PDC itself is a multiple CPU imbedded computer system. It is built using industry standard components and software support. This package specifically includes:

- 1 - 5 slot VME system in a 19" rack mountable chassis with 150 W power supply
- 2 - MVME162 CPU units with OS9 operating system installed
- 2 – 18 GB hard discs
- 2 – Ethernet ports with 10baseT connections
- 2 – 16 input serial ports, 8 on each CPU
- 2 – 5 port hubs for multiple network interconnection
- All required cables for system interconnection
- All software for PDC system operating functions described above

7.1.2 Typical PDC System Software Descriptions

The system will be fully configured and tested at the factory (BPA) prior to delivery. Four utility programs will be provided with the system. These are executable applications that run on a standard PC. They perform PMU testing, PDC monitoring, stored data plotting, and real time data display with archiving. Programs used in PDC are:

- **PMU Data Acquisition Program -** The PDC inputs data from PMUs or other data concentrators, correlates it by time and sample number, and writes it into a large buffer. The program "insert" performs this function. The buffer holds 1 minute of data to allow correlation of delayed data and pre-trigger data for disturbance recording. Data input can be Macrodyne, IEEE synchrophasor standard, or some other format. Input routines have been developed for Macrodyne and IEEE formats (due to lack of an IEEE format source, this input has not been tested, but will be when one is available). A text configuration file contains all the parameters for port setup, input formats, and data buffer setup. These parameters include things like port, BAUD rate, number of PMUs, Macrodyne/IEEE format, number of phasors, and data buffer length. The system reads this file at startup, so users can make system changes by editing this file and re-booting the system.

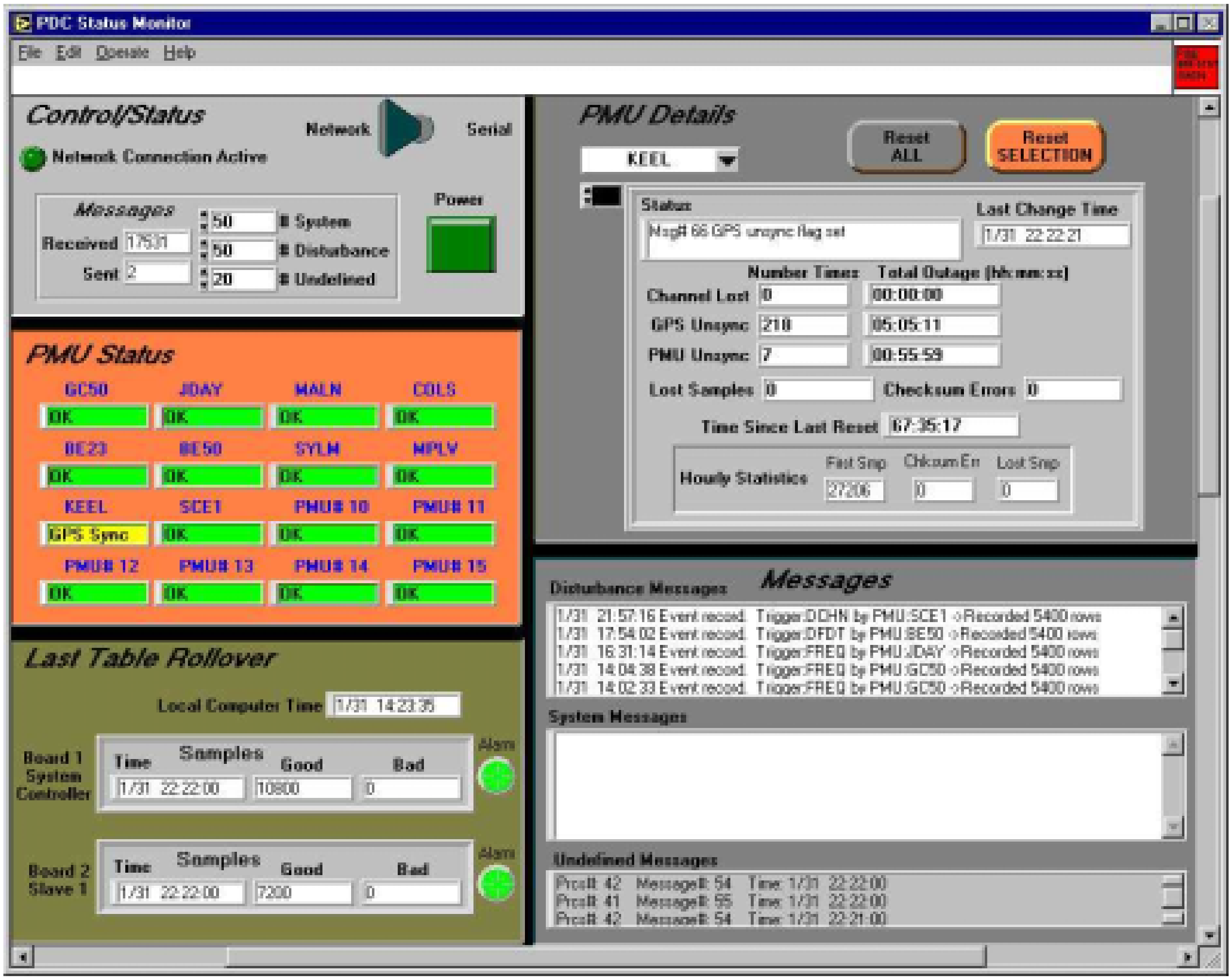
- **PMU Data Storage Program -** The PDC uses standard SCSI port, which will accommodate hard disks up to 4 GB without partitioning. A disturbance-logging program scans the input data for disturbances detected by a PMU. It records system-wide data in response to a disturbance detected by any PMU. It records 3 minutes of data with 55 seconds of pre-disturbance data. If the disturbance continues, the recording continues. The configuration can be changed for different length records. The PDC also resets the PMU for future triggers, and creates a disturbance log for easy review. The program "distlog" performs this function in conjunction with "insert". External devices connected to the PDC via Ethernet can provide extended storage.

- **PMU Data Broadcasting Program -** The PDC has an Ethernet port (and can have more than one) and the facilities for TCP/IP data communication. This port can be used for input or output. Currently a data distribution routine reads each row from the circular buffer as soon as it is filled (data from all PMUs has been inserted) and broadcasts the system-wide data sample using the UDP/IP protocol to any other application via Ethernet. The program "pdcstream" implements this function. (This message stream can be converted to TCP/IP for point-to-point applications.) Another output function provides processed phasor data to the SCADA master over a serial port (RS-232). This function emulates an RTU by responding to the required Master queries and supplying data in a SCADA format. This involves reading selected data from the buffer, deriving phase angles, voltage magnitudes and system frequency, formatting these values in the specific protocol, and transmitting the values to the Master. It also supplies status information in the form of digital indication points. The program "scadaout" implements this function. Other output functions can be built and run along with these existing functions.

- **PDC Self-Monitoring Program -** The PDC monitors itself and the remote data for errors and alarms. It keeps a log on disc of any PMU outage, loss of lock, transmission error, and routine failure. It will continuously display the status of the system and all remote units. It automatically sends commands to try to restart a PMU that has stopped transmitting. This function is provided by the program "errm". The PDC has a watchdog timer for its critical input processes that will reboot the system if any of them stop. The timeout is user settable up to 64 seconds.

- **PDC System Monitor Program -** This program provides a graphical display of the current system status and selected operational history as shown in Figure 20. It can be used remotely from the PDC on a suitable network. The current status display shows which PMUs have lost sync or have quit sending data, as well as those that are operating normally. It also shows if the PDC is operating normally, what its errors are, and the last few disturbances that have been recorded. There is an error history for each PMU including lost data, data errors, outage time and loss of sync time. The display uses visual alarms to alert the user to conditions that need further investigation.

Figure 20 – PDC Status Monitor Display



7.2 Typical SPM Application Server – See Figure 19

7.2.1 Typical SPM Application Server Hardware Description

The configuration shown in Figure 19 also includes a PC to be used for the dispatcher security monitoring displays and future applications, system monitoring, and data archiving. It is referred to as the SPM Application Server in Figure 19.

The PC provided in this package is a dual 866 MHz Pentium system with high-speed memory, disc, and video driver to enable it to perform simultaneous real time data display and data archive on disc. The data display is a strip chart format in engineering units with selectable traces and record length. The continuous archive function stores data for up to a specified number of hours, and then recycles disc space by erasing the oldest file and replacing it with a new one. In this way it operates continuously without user intervention while using a limited disc space. As supplied, this PC can be configured for up to 15 days of continuous archive. It can also be used for downloading and storing disturbance files from the PDC. It is equipped with a CD rewrite drive for longer-term data archive. It can also host the system monitor application.

The PC includes:

- 866 MHz dual Pentium III processor system
- 1 GB MB RDRAM-2
- 18 GB SCSI hard drive
- CD ROM, DVD, and Read-Write Drives: 8X/4X/32X IDE CD Read-Write – (DELL CDRW – [313-7586])
- 32 MB SGRAM video card
- 19” Trinitron display
- Sound card and speakers
- Dual 10/100BaseT network interfaces
- Mouse: Microsoft Intellimouse (2-button w/scroll) – (DELL I –[310-1270])
- Standard keyboard, floppy drive
- Windows NT operating system

The software for the SPM Application Server system will be installed and configured in the factory. This software includes programs for:

- Dispatcher Security Monitoring Displays
- PMU Testing Program
- SPM File Reader Program (LabVIEW GUI)
- PSM_Tools Batch Displays
- SPM Stream Reader Program

7.2.2 Typical Dispatcher Security Monitoring Displays

Real-time SPM data can be viewed with the Stream Reader and with various Security Monitoring Displays. Archived data can be viewed with several other tools, in a variety of ways. Examples of these displays are shown in Figures 20 through 23:

Figure 21 provides a visual overview of wide-area dynamic response in the Western Interconnected system. Relative bus angles are shown as rotating vectors, line currents are mapped to various colors, and strip charts show power across key interchanges. This work was intended as a proof-of-concept for providing a display of real-time network information collected from a network of dynamic monitors and phasor measurement units. Equivalent display will be created using both SCADA and SPM data.

Figure 21 Geographical Overview of Phasor Data Concentrator

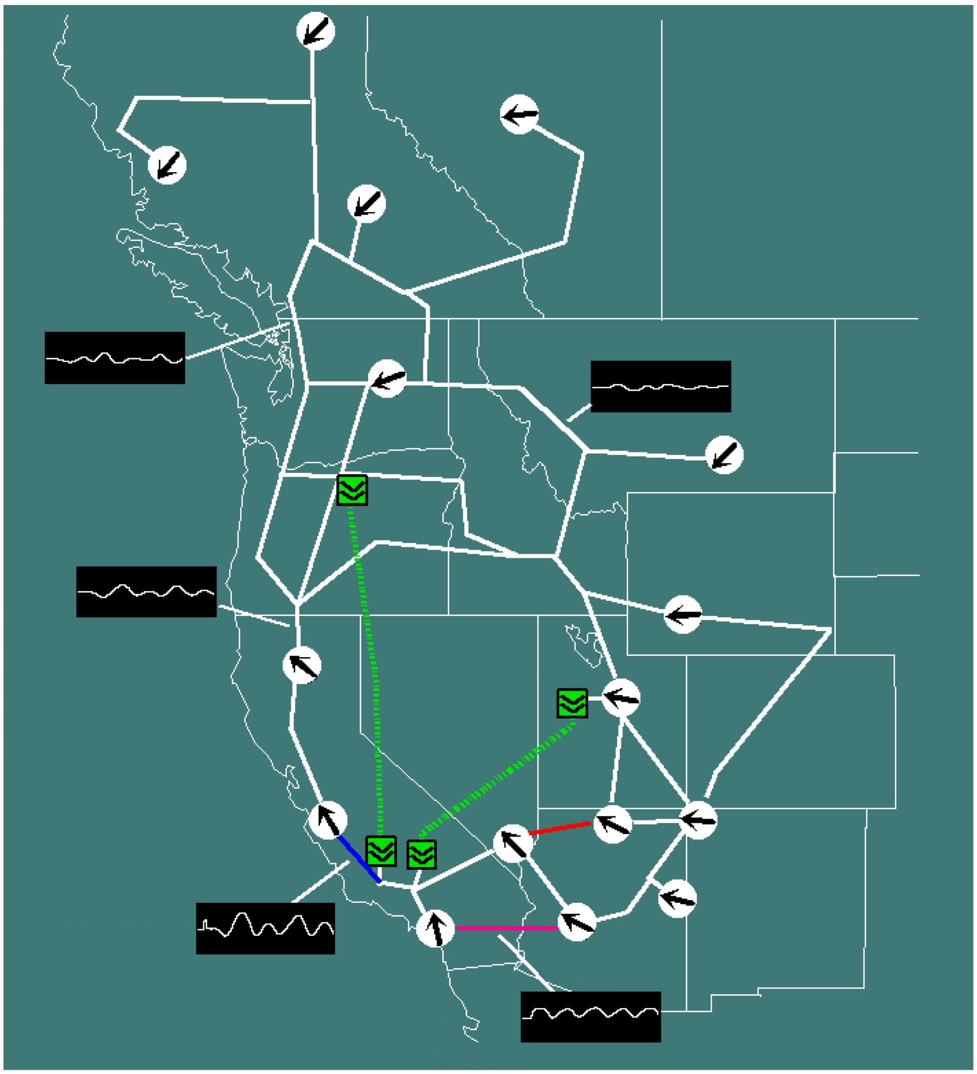


Figure 22 shows PDC data plots generated by the PDC File Reader program, a "virtual instrument" coded in LabVIEW. The display is scaled to engineering units and provides four time-correlated plots, each of which will support multiple traces. The plots can be printed with a complete legend and title.

Figure 22 Phasor File Data Reader Program

Figure 23 shows PDC data plots produced by one of the display options in PSM_Tools. The traces represent five PDC files joined together, and are accompanied by automatic documentation as to the source data and the processing used (e.g., bandpass filtering). Displays of this kind are commanded by means of preset menus indicating the signals of interest and the processing to be done.

Figure 24 shows the Synchronized Phasor Measurement Viewing Program capability to calculate the gain (stiffness) (MWs/per Hz) for the Midway-2 line to help in the post disturbance assessment. This screen can be used to calculate the changes of load, generation with respect to frequency or MVAR with respect to voltage for the disturbance file. Equivalent displays will be design to calculate parameters sensitivities in the near future.

Figure 23 - Viewing linked records with PSM_Tools for the WSCC oscillation event of August 4, 2000

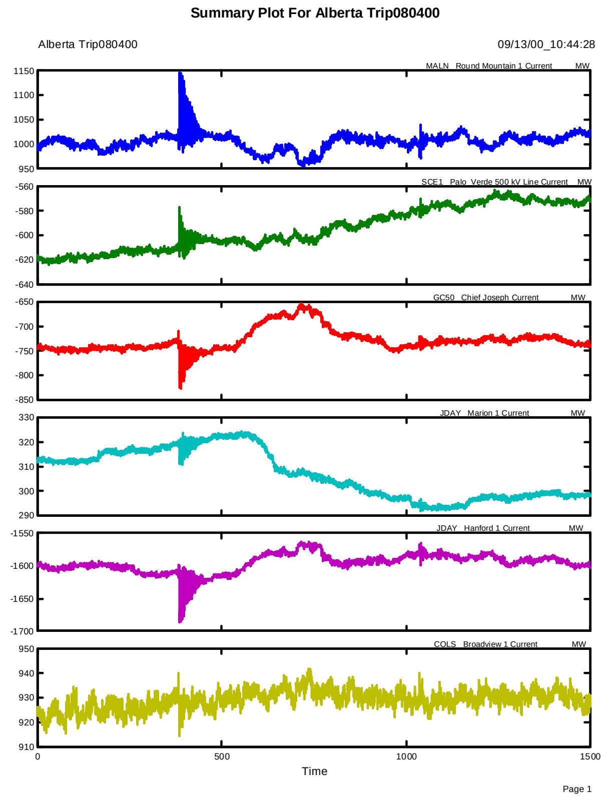
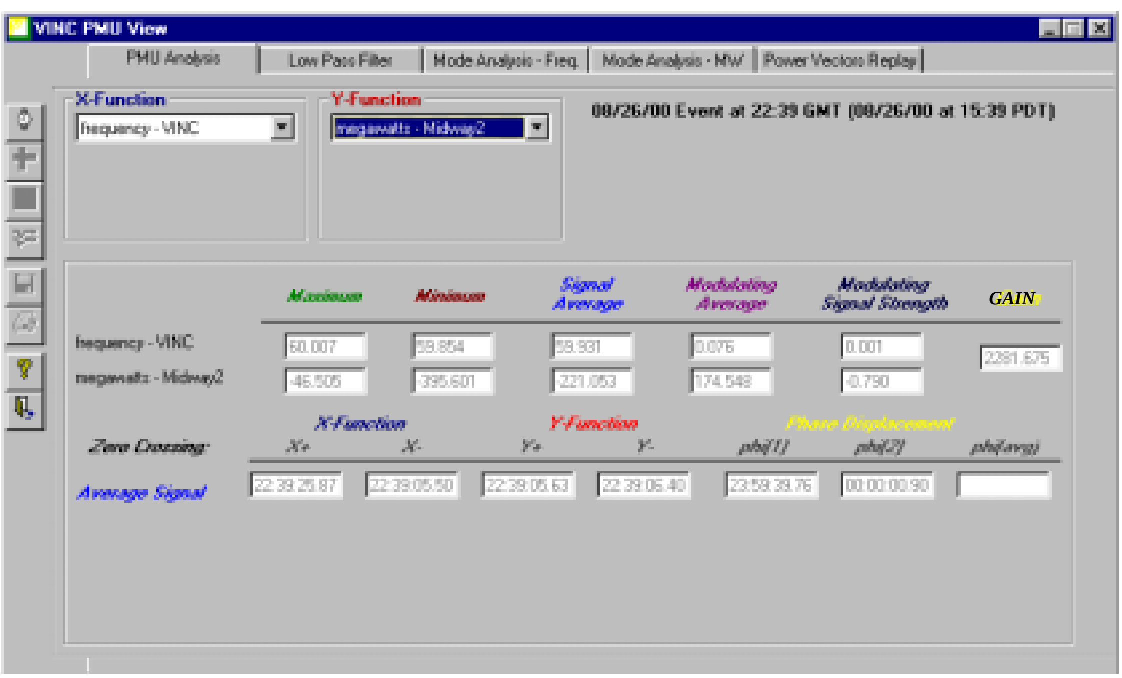


Figure 24 Vincent PMU Analysis Showing Gain (stiffness) for Midway-2 line

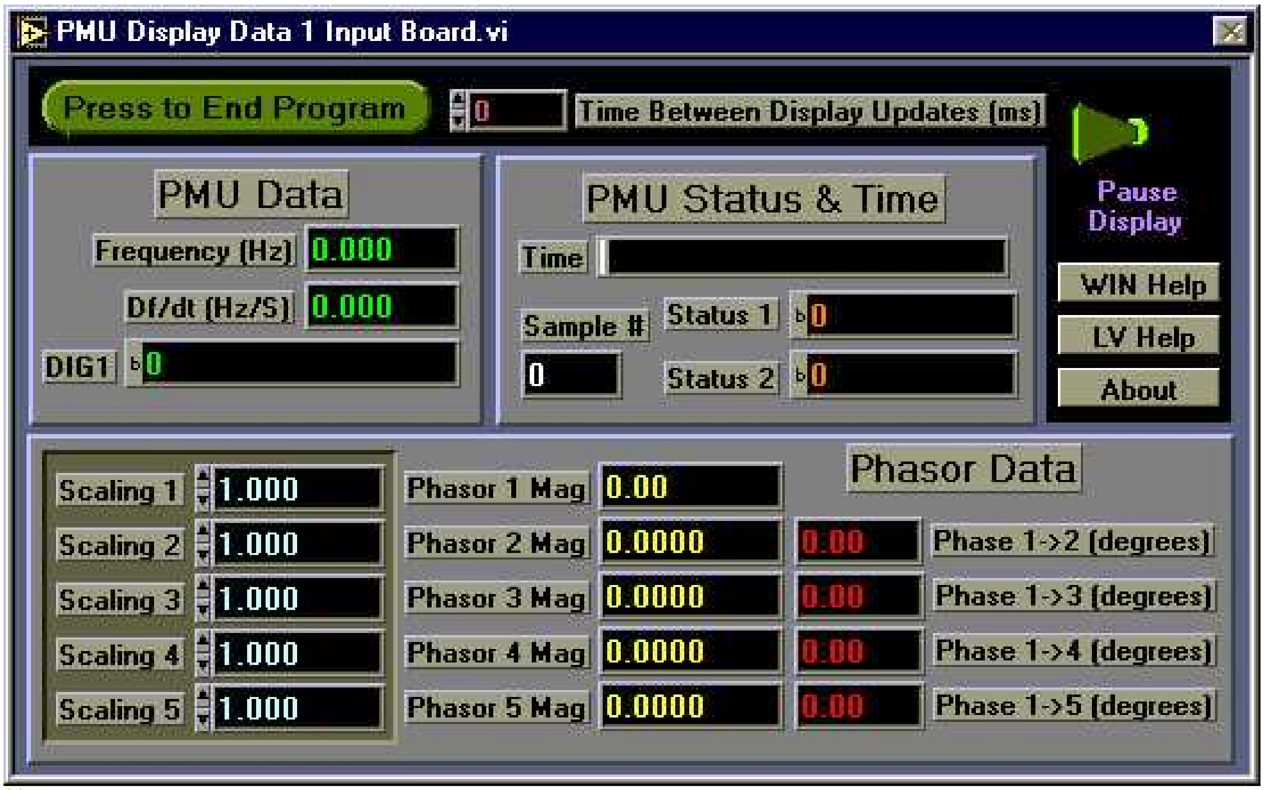


7.2.3 Typical SPM Server Maintenance Displays

7.2.3.1 PMU Testing Program

This program, shown in Figure 25 can be configured for Macrodyne PMUs. It displays the phasors in magnitude and relative phase angle format so the output data can be readily compared with local instrumentation. It also displays the PMU time, sample number, status, and digital indications. The phasor values can be scaled to match primary or secondary values. This program uses the PC serial input, so it can be used locally with the PMU or remotely via modem. It is very useful for PMU installation and calibration.

Figure 25 – PMU Testing Program



7.2.3.2 SPM File Reader Program

This program reads and displays data from a file recorded by a PDC. It incorporates an FTP client, which will download data from the PDC (or other) system using a simple menu selection. It will also read files from a selected directory. The data can be viewed in raw form in tabular format or as plots (Figure 22) scaled to engineering units stored in a configuration file. The graphical display has 4 time-correlated plots, each of which will support multiple traces. This allows comparing many parameters for determination of interactions. The plots may be printed with a complete legend and title.

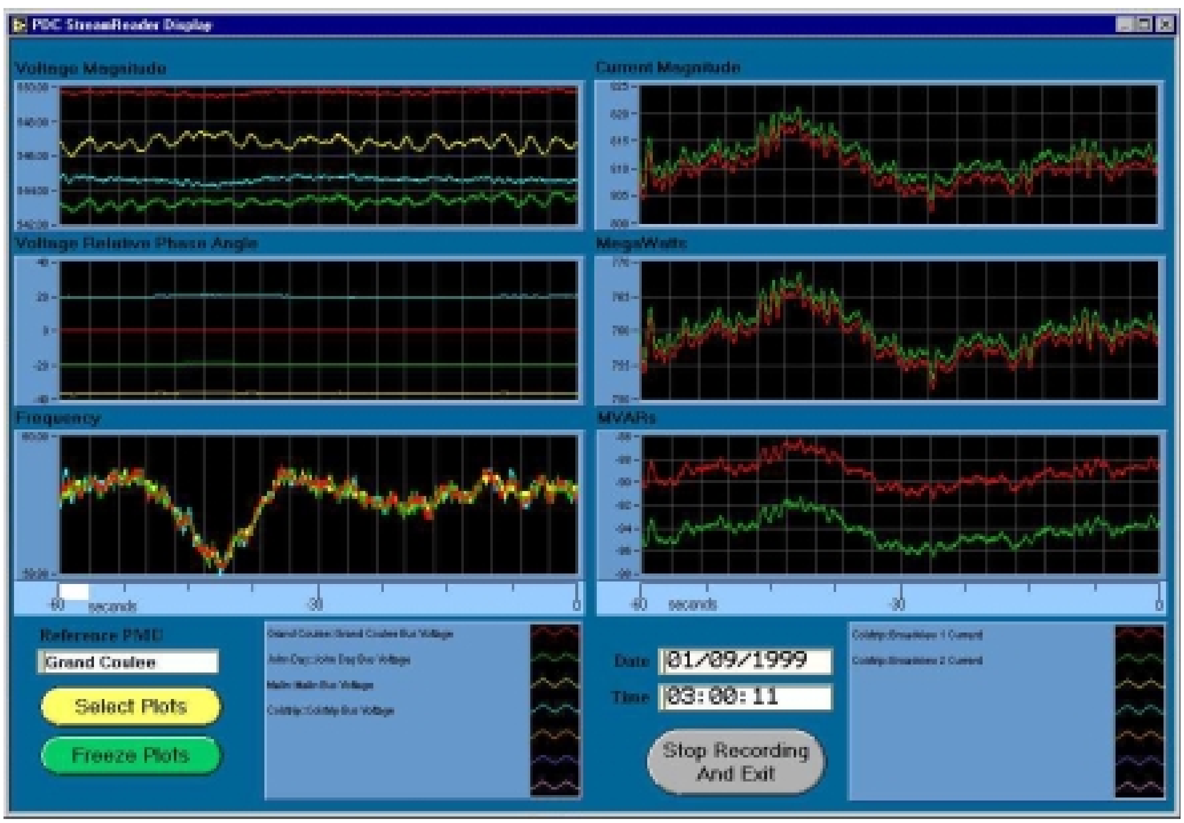
7.2.3.3 PSM Tools Batch Displays

Batch execution of Power System Monitoring Program (PSMTools) with variable parameters to display different signals for different devices. An example for this execution can be seen on Figure 23.

7.2.3.4 SPM Stream Reader Program

This program reads the real time data stream output by the PDC on Ethernet. It displays continuous plots of data scaled to engineering units from data stored in a configuration file as shown in Figure 26. The user may select which information to display as well as the graph time length. A continuous file recording capability is also included but it will only run reliably with the display on a fast PC. For typical PCs, these two functions can be run separately on different PC's. The continuous recording function records data in files on the PC disc up to the total hours of recording and then begins erasing the oldest file for the next file. The user may set the files size and number of hours to record. The user can retrieve data for events that were not recorded by other means as long as he does it before it is overwritten. For example, with a typical PMU setup of 8 PMUs, a 4 GB disc will hold 5 days of data, so the user will always have the 5 most recent days of data available.

Figure 26 – Phasor Data Stream Reader Program



7.3 Typical SPM Application Client for Operating Engineering Staff Personnel

7.3.1 Typical SPM Application Client Hardware Description– See Figure 19

In addition to the application server for Dispatchers, an application client for Operating Engineering will be configured for monitoring and processing phasor data for system dynamic identification and post disturbance assessment purposes. Initially data will be made available from SCE and BPA as recorded files posted on their respective web FTP sites. The client will be configured to access these sites. Later in the project when the rest of the system is installed, the client will be able to directly access the PDC data by network from the SPM Application server and the PDC itself as shown in Figure 19. Since the primary purpose of the client is data processing, it will be equipped with the stream reader and file reader applications, and the DSI Toolbox containing the conversion and analysis tools developed by PNNL and BPA and some of the related SCE displays. It will also have Matlab installed, as it is required to run these tools.

The technical requirements for the application sever hardware are generally a PC with at least 100 MB of RAM and enough disc space to hold a number of archived records. The recommended system below will have very satisfactory performance and enough disc storage to keep a sizeable data archive. With the specified Zip drive and CD ROM burner it can be used for making data archives and data exchanges to other machines. Recommended PC client configuration:

- 933 MHz Pentium III processor system - (DELL 4T933 – [220-2932])
- 1 GB PC600 MB RDRAM-2 (4RIMMS) - (DELL 1GN34 –[311-3911])
- 2 - 18 GB Ultra 160/M SCSI (15,000 rpm) hard drive – (DELL 18S15- [340-3711])
- 250 MB Iomega Zip drive
- CD ROM, DVD, and Read-Write Drives: 8X/4X/32X IDE CD Read-Write – (DELL CDRW – [313-7586])
- 32 MB SGRAM video card
- 19” monitor
- Sound card and speakers
- 10/100BaseT network interface
- Mouse: Microsoft Intellimouse (2-button w/scroll) – (DELL I –[310-1270])
- Standard keyboard, floppy drive
- Windows NT operating system
- MatLab

7.3.2 System Dynamic Performance and Post Disturbance Support Application Software

The software will be installed according to manufacturer’s recommendations and standard practices. Network connections will be made on-site when the system is delivered. Programs will be set up and tested prior to delivery in so far as is possible. The specific software that will be installed is:

- PSM Tools
- Ring Down Graphical User Interface
- Synchronized Phasor Measurements Viewing
- Archive Scanner
- Future Nomograms and Remedial Action Schemes (RAS) validation

Each of the software applications is briefly described below except for the stream reader and file reader applications, which are described under section 7.2.1.

7.3.2.1 PSM Tools (MatLab) – See Figure 27

The DSI Toolbox contains a number of individual 'tools', which are detailed below. The Power System Monitoring (PSM) Toolset is the latest Matlab version of a BPA tools package that has supported BPA and WSCC monitor operations since 1975. The toolset accepts data from BPA's PDC, PPSM, and PSAM monitor technologies, plus a variety of other sources. In its present form, PSM_Tools provides a standardized "interactive batch" environment that is oriented toward high volume analysis, with functionalities and interfaces that are expressly designed for dynamic systems analysis in planning or control engineering. Selected modules can probably be adapted to near-real-time use through dynamic link logic.

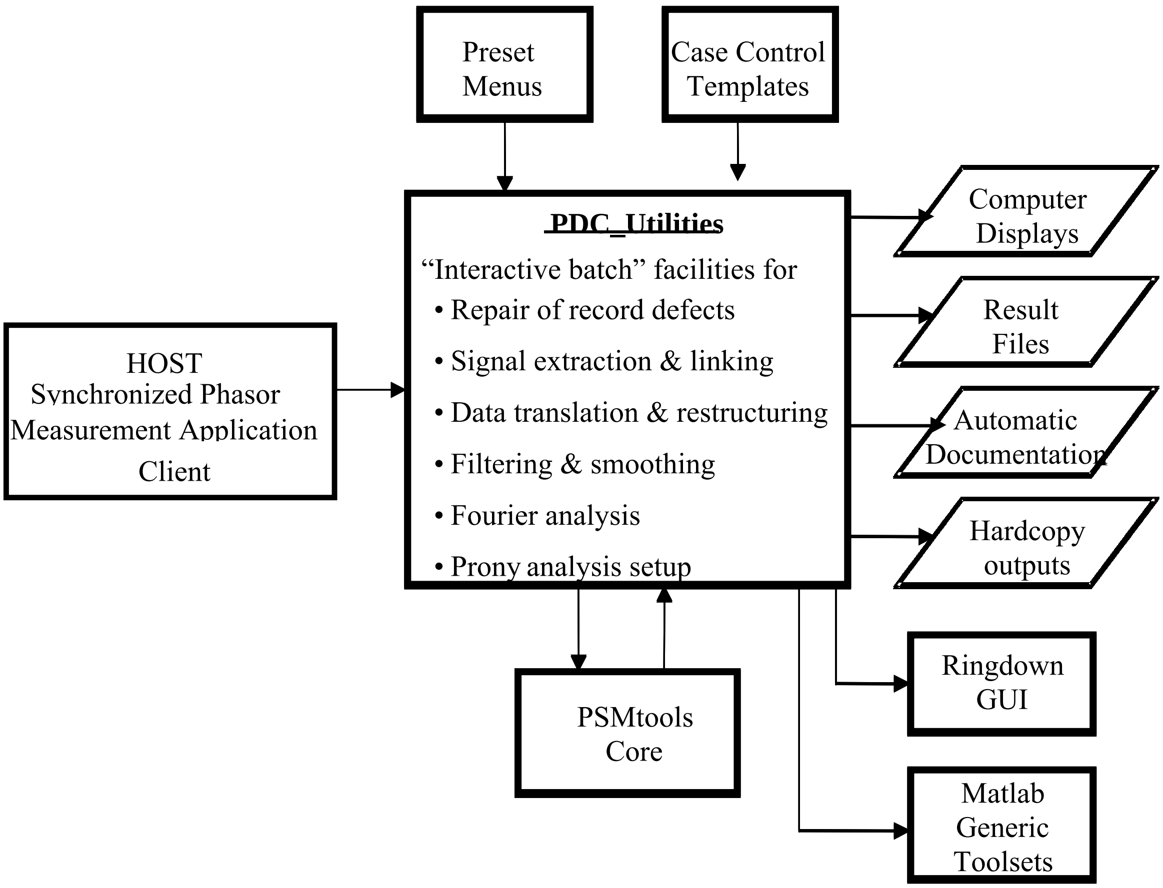
The PSM_Tools "core" performs essential functions such as records integration, display, filtering, spectral analysis, hardcopy plotting, and saving of data into standardized file structures for later use. Processing logs are generated automatically, and summary logs are incorporated into all hardcopy or file results. This core provides a single framework in which the user can view and process power system response records from any source for which an appropriate data translator is available. It also provides interfaces to more advanced elements of the PSI Toolbox, and to the many add-on toolsets for signal analysis, controller design, and other advanced tasks. Within PSM Tools, PDC Utilities is a translator and preprocessing package that imports PDC data into the PSM Tools environment. The processing can start with binary records taken directly from PDC archives, or with records that have already been translated into one of several Matlab formats by some external process. Special functions include the following:

- Logging and repair of data defects due to messages lost in the digital communication system
- RMS Calculations that convert the phasor data into engineering quantities such as voltage magnitude, real and reactive power, relative angle and relative frequency
- Alignment & integration of composite records extracted from multiple PDC units

PSM Tools Next Generation

Dispatcher use of PSM_Tools will require future custom modifications specific to the data environment and the workflow pattern. Likely elements in this include special links and translators for source data, custom menus for treating the data, and more interactive displays. This will require some custom code plus translation of present "dialog box" interfaces into custom GUIs, and perhaps the development of real-time drivers for PSM_Tools.

Figure 27 – PSM_Tools Structure



It is also likely that PSM_Tools and other elements of the PSI Toolbox can be adapted to real-time use. Within the framework of Figure 2, the most immediate application for the PSI Toolbox is processing of archived data. However, functionalities offered by the PSI Toolbox are also needed in all processing paths downstream of the circulating signal processing buffer. The three indicated displays could be provided through a data access link plus adequate processing power. Better integration might result from special LabVIEW or Visual Basic drivers for selected Matlab elements of the PSI Toolbox, however. Mixed use of such codes is a recent and rapidly evolving option for WAMS technology development, and one that needs early attention.

7.3.2.2 Ring Down Graphic Interface User (GUI) Program (MatLab) – See Figures-28, 29 and 30

The Ring down Graphical User Interface (GUI) is contained within the Power System Identification (PSI) Toolbox developed by the Bonneville Power Administration (BPA) and the Pacific Northwest National Laboratory (PNNL). This is the latest Matlab version of BPA systems analysis tools that trace their origins to wide area control projects in the mid 1970's, and that have undergone extensive use and refinement since that time.

The Ring down GUI is an interactive tool for examining the oscillations that often accompany system disturbances, staged tests, or planning model simulations. Oscillation components are described in terms of their frequency, damping, strength, and relative phase (see Figure 1). Associated linear models are provided for use in continued analysis, which might include the validation of planning models or the engineering of stability controls. The mathematical software underlying the Ringdown GUI is based upon a broad menu of options for extended Prony analysis, with options for accessory use of filtering and Fourier analysis. Future use of the Ringdown GUI may also include subspace projection methods for use in analysis of forced system response.

Figure 28 - Oscillation analysis for the WSCC breakup of August 10, 1996. (Typical screen graphic for the Ring down GUI)

Figure 29 – Oscillation Analysis for the Alberta trip oscillation of August 4, 2000

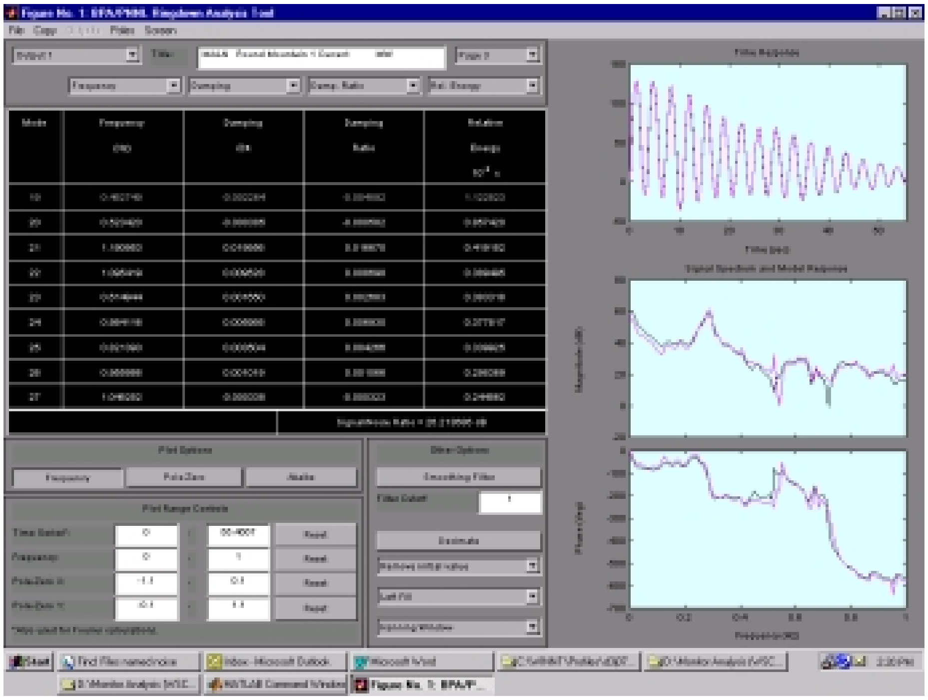
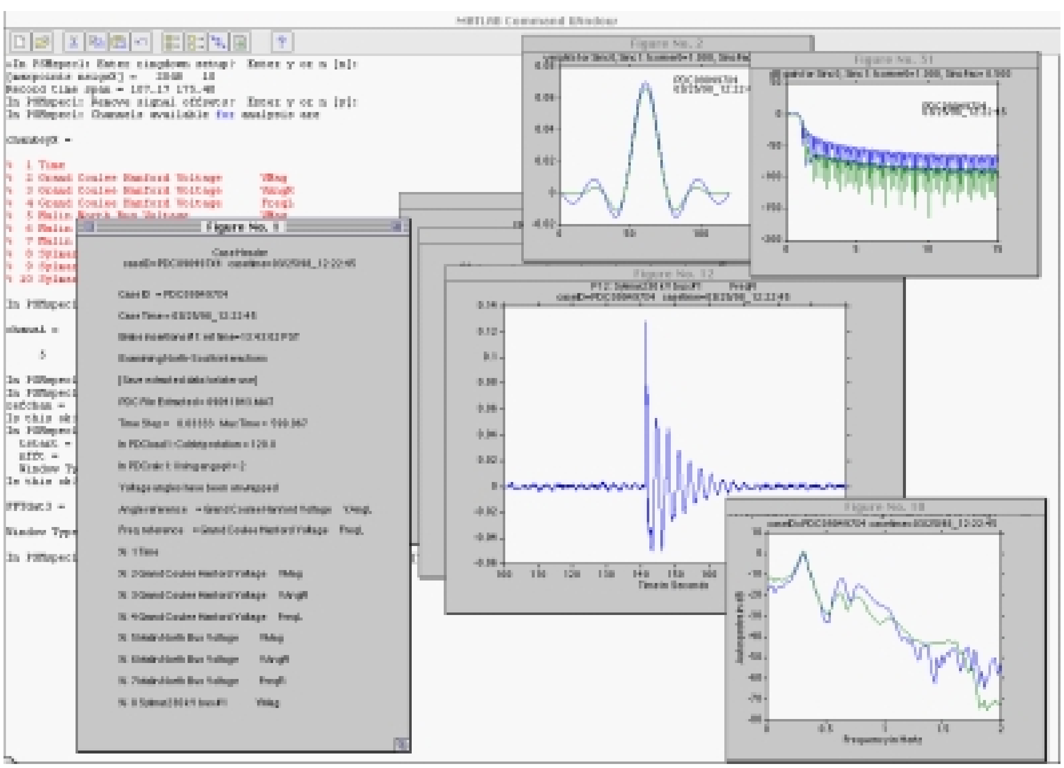


Figure 30 - Frequency-domain viewing of ring down signals.

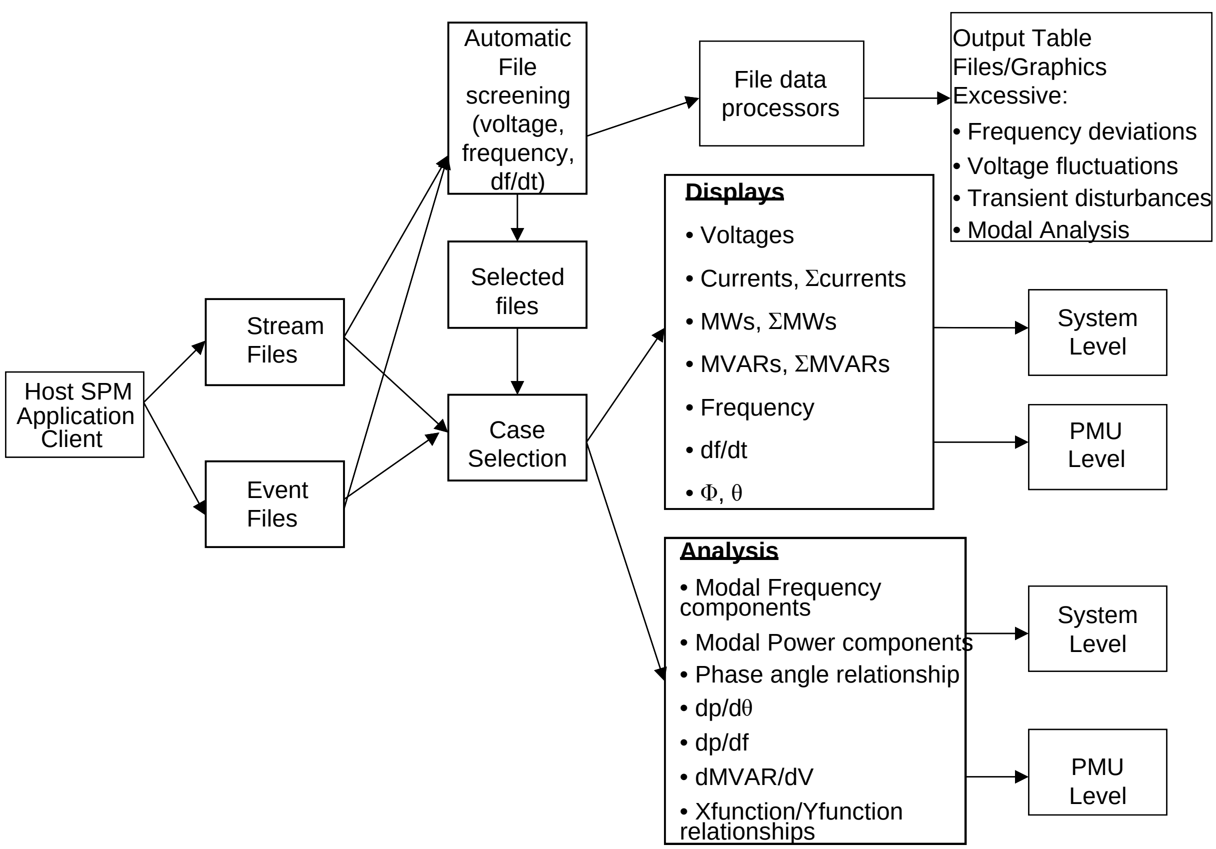


7.3.2.3 Synchronized Phasor Measurements Viewing Program (Visual Basic) – See Fig. 31

This is the program developed by Southern California Edison (SCE) to view data files created using Synchronized Phasor Measurements (PMUs). Figure 31 shows and overview of the SPM Viewing Program. Disturbance, events and continuous (stream files are created and stored in the Phasor Data Concentrator (PDC) whenever there is a disturbance in the system and the frequency.

The SPM Viewing Program was designed to address two major functional categories, Security Monitoring displays and application software for analysis. The SPM viewing software is capable of viewing disturbance data files and provides to the user different displays for voltages, currents, sum of currents, megawatts, sum of megawatts, megavars, and sum of megavars, frequency and variation of frequency. The modal analyses for frequency and power components are also part of the functions of the program. The program also can calculate the "stiffness" factor (MWs/Hz) for the lines. The capability of the software can be seen from some of the plots shown in 'Sample Process and Displays for Post Disturbance Assessment', Attachment A. Those specific records are from the event recorded on August 26, 2000 at 15:40 PM PDT when the Palo Verde Unit 2 relayed while carrying 1245 MW.

Figure 31 – Synchronized Phasor Measurements Viewing Program



Attachment A contains sample displays coming from the SPM Viewing program as used for post disturbance assessment.

7.3.2.4 Archive Scanner Program – See Figure 32

The WAMS Archive Scanner is an extended version of PSM_Tools that automatically examines the information content of archived data. Key functionalities include the following:

a) Continually updated displays of time-domain and frequency-domain features, emulating those that would be seen for a real-time data stream.

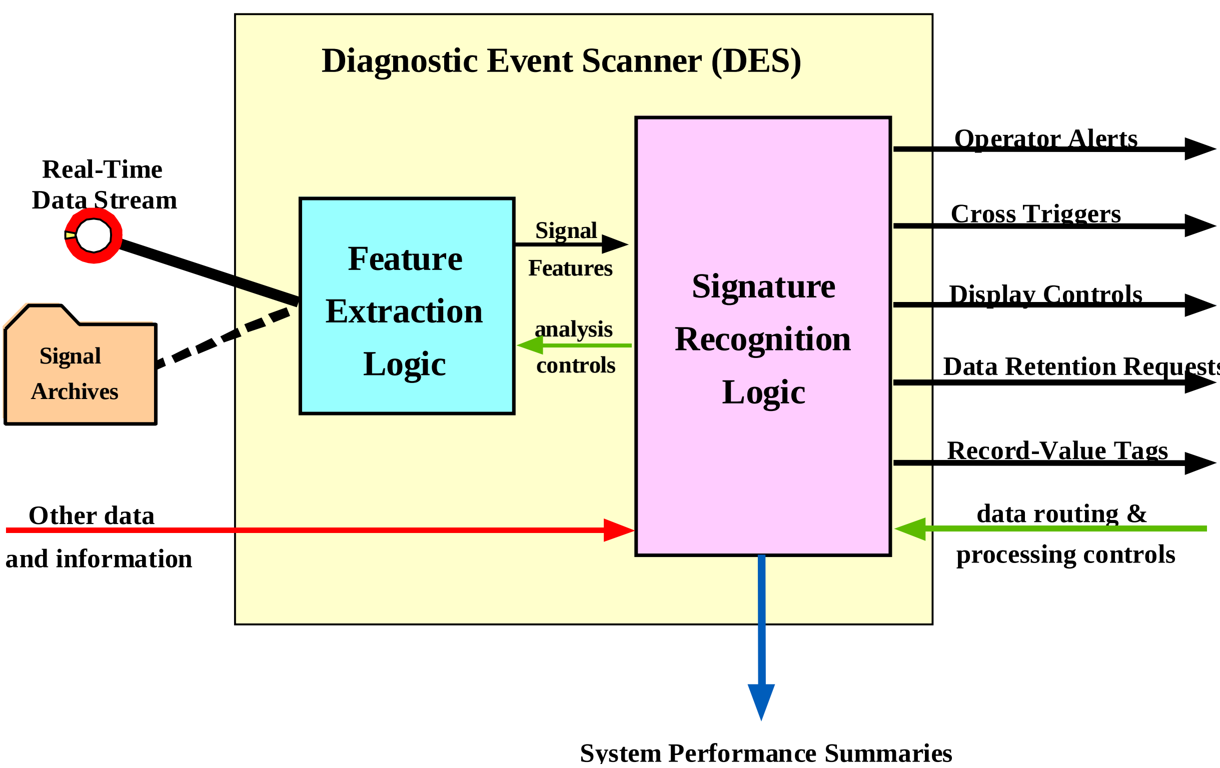
b) Tables and optional displays for abrupt system changes, to include time of occurrence plus summary descriptions.

c) Basic statistical summaries of system dynamic performance.

d) An initial version of the signal recognition logic indicated in Figure 32.

Expanded versions of functionalities (c, d) can be developed as the HOST information needs become better known. It seems likely that functionality (c) would be useful for developing summary information required by NERC, and that some elements of the WAMS Archive Scanner may be usefully applied to general EMS data.

Figure 32 - Functionalities of a Dynamic Event Scanner (DES)



7.3.2.5 Future Applications (2001-2002) - Nomograms and RAS Validation Programs

During phase-2 the following applications will provide operating authorities with a set of tools to effectively monitor the security or reliability of the grid. The three major future dispatcher performance monitoring applications using SPM will be:

- Stability Dynamic Loading Monitoring (application will complement the current static stability nomograms) – Currently, the Dispatcher or an EMS program takes actual line or path loading and plots it on a static stability nomogram to determine if the system is operating within limits, based on prior studies. The performance monitoring application, using real time SPM data, will compare the phase angle between critical busses to validate if the system is actually operating within limits or advise the Dispatcher that limits are being exceeded. The application will also serve to validate the nomograms. Over time and after gaining confidence with this application the static nomogram potentially could be replaced and transfer capability decisions could be made based on the information received from the SPM's.
- Remedial Action Schemes (RAS) Monitoring - Currently, remedial action schemes are designed to operate based on input from the status of the circuit breaker(s) associated with the lines or path. The assumption is that based on off line studies there is a high probability that the system becomes unstable after the loss of a critical transmission element. The performance monitoring application, using real time SPM data, will compare the phase angle between the critical busses, during or after the loss of a transmission line, to determine if in reality the system would have become unstable and also will be used for RAS validation purposes
- Preventive Disturbance Monitoring - Dispatcher monitors near real time instability predictions calculated using SPM data. This would provide the dispatcher with advanced warning of potential unsafe conditions and allow them to define and execute the necessary preventive operational actions.

7.3.2.6 Future Operating Engineering Applications Using SPM (2001 – 2003)

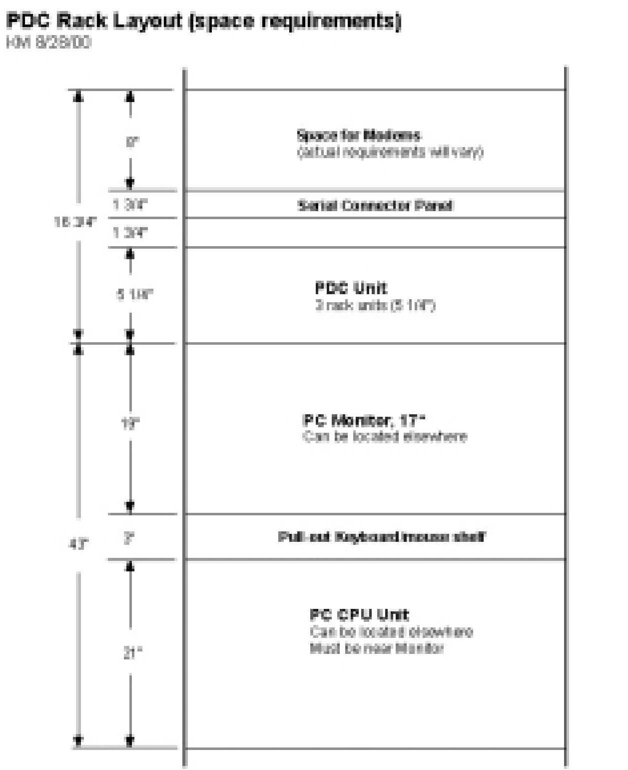
During phase-2 the following support applications will be deployed:

- Areas State Estimation. Using the current set of WSCC Synchronized Phasor Measurements, area state vectors will be calculated for those regions of the System where currently enough phasors are available. The goal is to make available for dispatchers critical system monitoring data that is more accurate and reliable than is currently produced by software-base state estimators.
- Event Recording (Disturbance Signature) - Develop a database of disturbance signatures to use for use further development of phasor measurements based applications and grid automation.
- Fault Location Analysis

7.4 PDC System Installation Requirements

The PDC system is communication intensive and is best located conveniently to the majority of its communication connections. This usually means it needs to be located with good access to the modem input connections. The PDC unit and serial patch panel are designed for mounting in a standard 19” rack. They can be located otherwise as long as cooling and cable connection requirements are met. The patch panel connects directly to the PDC with ribbon cable, so they need to be directly above/below each other. The serial connections to the modems should be less than 10’, but can be longer using special cable. The cables connect at the front of the panel. The network and power connections are at the rear of the PDC. The network connections can be up to up to Ethernet specifications for 10BaseT. The PDC requires standard 120 VAC electric power, under 200 W. Cooling input is on the front and output is on the top rear. Figure 33 shows the layout dimensions, including requirements for mounting the PC in the 19” rack. The PDC unit is about 18” deep; the serial panel is 2” deep. Depth of the other units depends on the shelves and the particular units provided.

Figure 33. PDC System Layout for Mounting in a 19”rack.



Suggested layout for mounting system in standard 19" rack. PDC unit and Serial Connector Panel are designed for rack mounting and require only screws; other items require rack shelves for support. PDC Unit, serial connector panel, and modems should be co-located; all PC units should be co-located.

The PC shown is the unit designated SPM server in Figure 33. It is a standard office type system with a 19” monitor and mid-size tower CPU. It should be located anywhere convenient for operator use. As shown in the diagram, it has one serial and two network connections to the

PDC. The system does not require the serial connection, though it can be handy for problem solving. The usual network configuration puts the file and administrative access for the PDC on a standard corporate network and the broadcast data stream on a separate network. This allows many users access to data as well as PDC administration access without special cabling. The data stream output can introduce a large amount of traffic and is best separated into its own sub-net. It can co-exist with standard network traffic if there is sufficient bandwidth to accommodate it. If the two networks are to be kept separate, two network connections are required on the monitor PC. The PC requires standard 120 VAC electric power.

The stream reader application is required for the SPM Client PC. If the data stream is on a network separate from the administrative network, a second network card will be required for this PC as well. This should be added to the Client PC requirement list. If it is anticipated that the client PC will be used for data stream display and archiving, it may be necessary to use a higher capability PC than that specified.

7.5 Additional Hardware and Communications Notes and Requirements

The initial inputs from the PDC units at BPA and SCE will be over serial communication links at 56 KBPS or less. Only part of the phasor measurement data being received by these PDCs can be sent on these serial links. The system is set up to send two phasors, frequency, and status from selected PMU inputs to each PDC. The number of PMU data blocks that can be sent depends on the speed of the data links. A reliable 56 KBPS link will allow sending this data subset from up to 10 PMUs from one PDC to another. At this time, BPA and SCE have only 8 and 9 PMUs in service respectively, so a 56 KBPS link is sufficient. When higher speed communication becomes available, the entire data sets can be sent to the HOST, though PDC modifications will be required to accommodate this change.

Modems and other communications are not supplied with the PDC system. The serial communications must conform to EIA standards for RS232, including voltage levels, connectors, and bit rates. It is recommended that leased line modems are used, or any other type that automatically establishes connection to the modem at the distant end. The PDC units do not initiate any dial-up or connection procedures. (This functionality could probably be added at extra cost). Communications should be specified and implemented working with BPA engineers to be sure they will be compatible with PMU and PDC operations.

The PDC communicates over networks using TCP/IP protocols. It will host both telnet and ftp sessions. It requires a fixed IP address, which needs to be compatible with the local network on which it will be used. If this is supplied to BPA before delivery, the system can be configured and tested with this address.

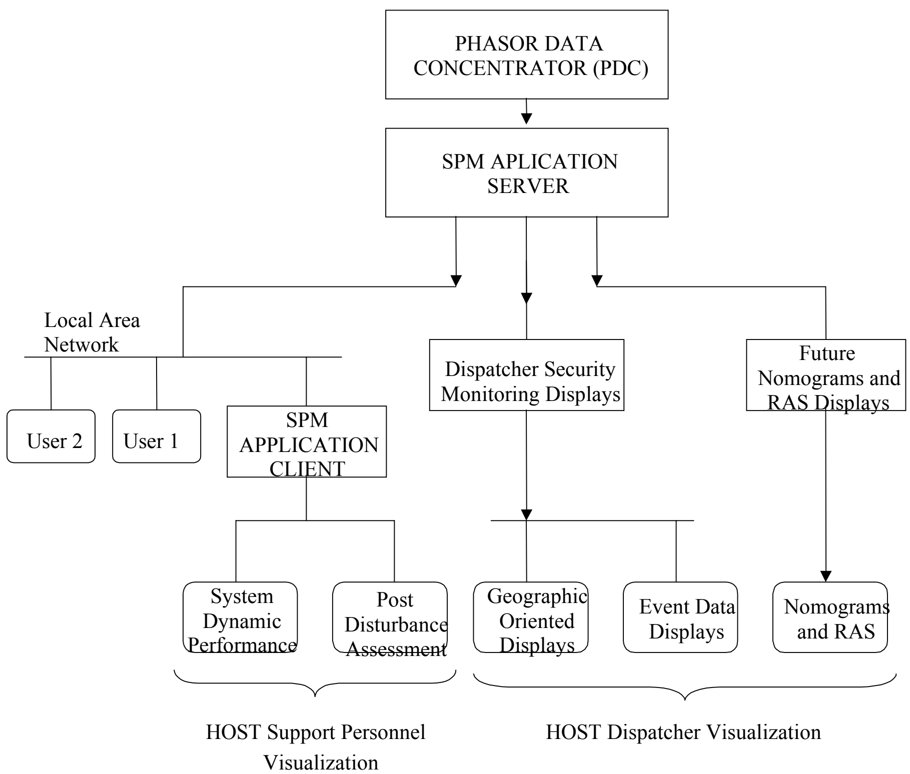
Some of the equipment used in the system requires about a 60 day lead time on ordering and cannot be pre-stocked by BPA. Consequently, the system delivery will be set for 70 days after order has been placed with BPA.

8. TYPICAL HIERARCHICAL PHASOR DATA VISUALIZATION

Each of the three sets of SPM applications, the dispatcher security monitoring displays, system dynamic performance and post disturbance assessment identified for HOST, have a corresponding set of displays as shown in Figure 34.

- Dispatcher Security Monitoring Displays – In a preliminary basis three subcategories of displays have been identified one subset of system geographic-oriented displays showing SCADA and SPM data, a second subset of event displays showing sensitivities for certain system parameters and a third set of monitoring displays with the capability for displaying any phasor data.
- System Dynamic Performance Displays – Detail descriptions and corresponding Figures are in Section 7.3.1.2 and 7.3.1.3.
- Post Disturbance Displays Assessment Displays – Detail descriptions and corresponding Figures are in Section 7.2.2.1

Figure 34 Typical Synchronized Phasor Data Visualization Requirements



The proposed visualization arrangements have been defined based on, first, some of the displays created at SCE and BPA for their current synchronized phasor measurement infrastructures, and second, the visualization requirements for some of the new applications being proposed in this specification.

Some of the displays contents have been defined using the CERTS display-creation methodology described in Table-6. For new displays answers will be identified and discussed with the three fundamental questions from the table. WHAT parameters are being monitored, WHY the parameter is beyond specified threshold, and what operational ACTION, if any, needs to be taken to return the performance parameter back to its normal state.

Table-6 – Methodology to Define Contents of Proposed Visualization

Visual Analysis / Tools Horizon	*WHAT* is Happening	*WHY* It is Happening	*ACTION* Corrective Predictive
Performance	Dispatcher monitors difference between paths stability points calculated with SPM and Nomogram	Nomogram is predefined and SPM is a real time measurement	Dispatcher can relieve or further constraint path transfer limits
Tracking	Dispatcher tracks difference between paths stability points calculated with SPM and Nomogram	Nomogram is predefined and SPM is a real time measurement	Dispatcher corrects Nomogram
Prediction	TBD	TBD	TBD
Support Studies	TBD	TBD	TBD

9. HOST RESOURCES REQUIRED, TRAINING AND DOCUMENTATION

CERTS has identified the following HOST organizations with which there will normally be close coordination for successful deployment of the system and adequate production of users training and documentation:

- HOST Research Group – Acting as a Liaison and coordinator between CERTS people leading deployment of the System and the HOST organizations described in the following bullets

- HOST Dispatching Office – CERTS will demonstrate the dispatcher security monitoring displays to the dispatchers. Jointly they will define and agree on appropriate changes to this specification and for displays. Future phasor security monitoring applications for phase-2 will be also reviewed with them.

- HOST Operating Engineering and /or Training Office – System dynamic performance and post disturbance assessment displays, processes and methodologies will be reviewed and discussed with HOST personnel to identify the most effective training processes and documentation guides. CERTS recommends that the SPM Application Client System be implemented and used for review, and specifically for training for this particular group. This can be done even before the complete HOST system is deployed.

- HOST Information Technology and Data Communication Offices – CERTS will need to review in detail Section 7 of this specification with these two organizations. A high level of coordination and interface will be required on this area for hardware acquisition, data communication issues, hardware integration and overall interface of this system with other HOST infrastructures.

GLOSSARY

APS – Arizona Public Service
BPA – Bonneville Power Administration
CAISO – California Independent System Operator
CERTS – Consortium for Electric Reliability Technology Solutions
GUI – Graphic User Interface
LADWP – Los Angeles Department of Water & Power
LBNL – Lawrence Berkeley National Laboratory
ORNL – Oak Ridge National Laboratory
PDC – Phasor Data Concentrator. Collects data, controls, monitors and archives phasor measurements.
PG&E – Pacific Gas & Electric
PMU – Phasor Measurement Unit. "Intelligent" digital transducer designed to extract phasor quantities from point-on-wave voltage and current measurements
PSM – Power System Monitoring
RAS – Remedial Action Schemes
SCE – Southern California Edison
SPM – Synchronized Phasor Measurement
SRP – Salt River Project
WAPA – Western Area Power Administration
WSCC – Western System Coordinating Council

REFERENCES

[1] B. Bhargava, **Synchronized Phasor Measurement System Project at Southern California Edison Co.** Los Angeles, California, May, 1999.

[2] J. F. Hauer, W. A. Mittelstadt, D. J. Maratukulam, W. H. Litzenberger, and M. K. Donnelly, **Information Functions and Architecture for Networked Monitoring of Wide Area Power System Dynamics: Experience with the Evolving Western System Dynamic Information Network.** WAMS Working Note, Draft of June 25, 1997. Produced under a BPA/EPRI Tailored Collaboration within the DOE/EPRI Wide Area Measurement System Project.

[3] K. Martin, **Summary Descriptions of the BPA Phasor Data Concentrator (PDC).** Portland, Oregon, February 2000.

[4] **Synchronized Phasor Measurements for WSCC.** Prepared by Virginia Tech, Center for Power Engineering for Electric Power Research Institute, May 1997.

[5] **WSCC Plan for Dynamic Performance and Disturbance Monitoring.** Prepared by the WSCC work Group. September 15,2000. (Included as Attachment B).

ATTACHMENT A

Sample Process and Displays for Post Disturbance Assessment

Plots in Figures 1 to 12 show the disturbance that occurred on Saturday, August 26, 2000 at 15:39 when the system experienced a disturbance caused by the tripping of Palo Verde unit. Below are the records from the SCE Phasor Measurement System for the disturbance.

The system frequency according to the ECC report dropped to 59.87 Hz momentarily and normal in 42 minutes at 15:40 PM PDT when the Palo Verde Unit 2 relayed while carrying 1245 MW. However, the actual record shows the frequency dropping further to 59.844. The disturbance files are created for a period of three minutes, with one minute of pre-disturbance and two minutes of post disturbance. The PMUs record the frequency at each PMU location. The signal from Mohave PMU was not being received at this time by the PDC because of some work in progress on the communication line.

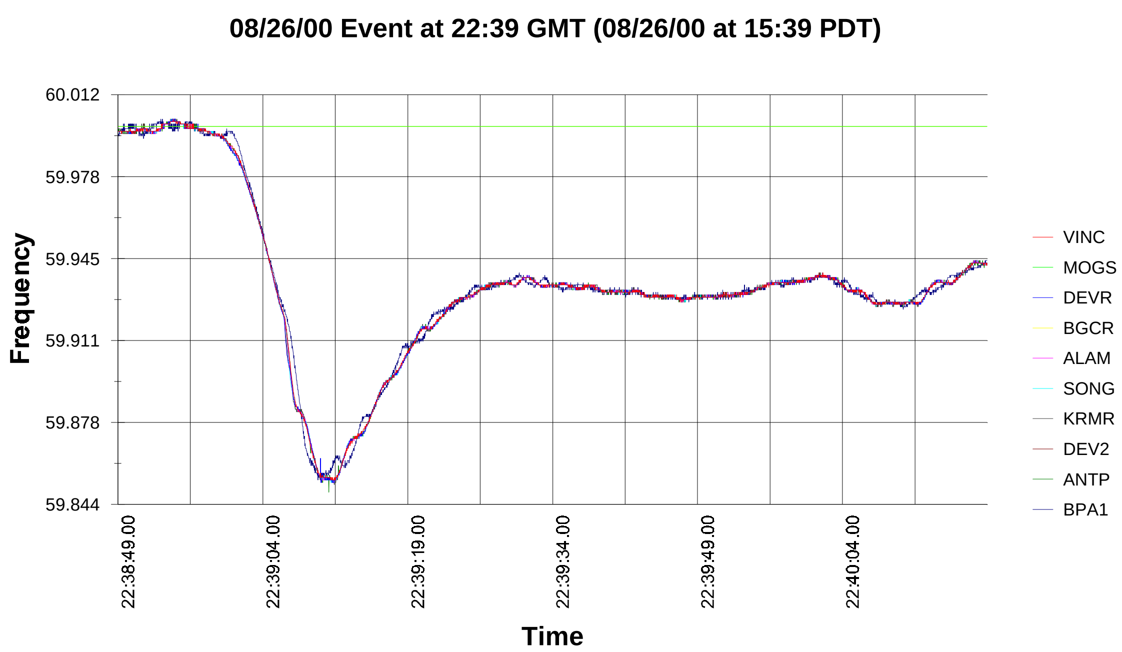


Figure 1 - Frequency recorded by different PMUs in SCE and BPA area.

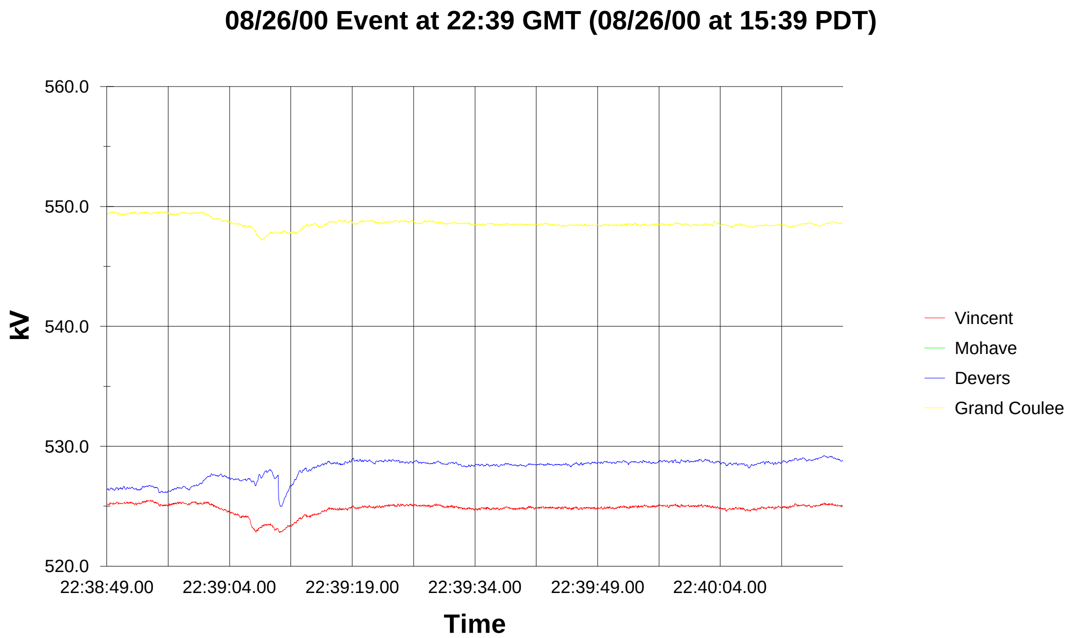


Figure 2 - Plot showing the 500 kV voltages at Devers, Vincent and Grand Coulee (BPA) stations.

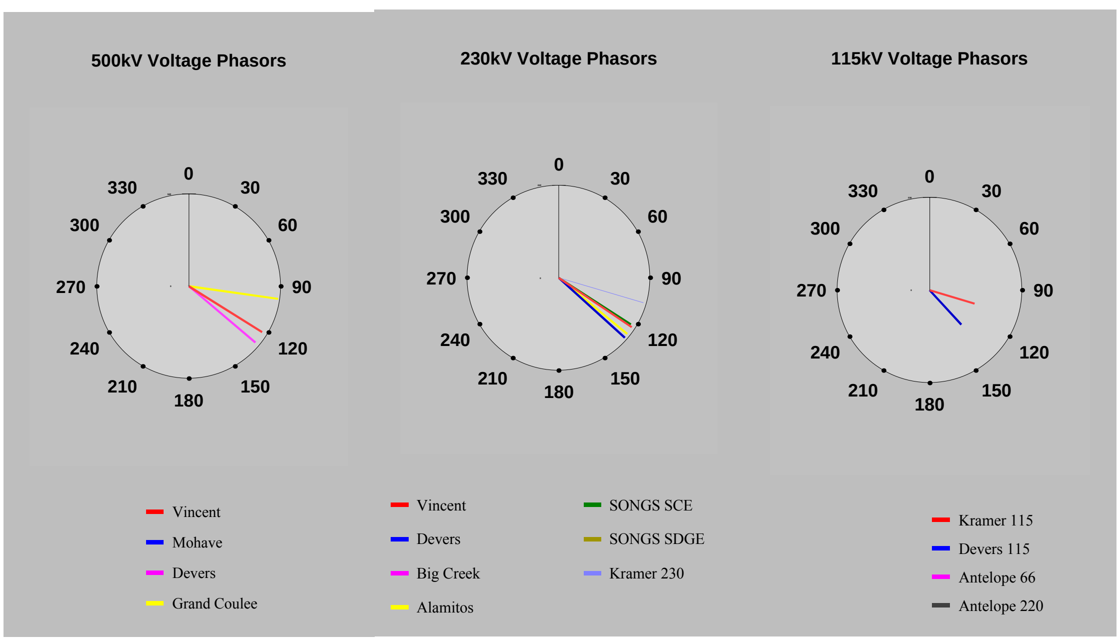


Figure 3: Voltage phasor Phase angle relationship of different SCE and BPA phasors. The figures also show the phasor magnitude. Wide angles between the generating stations can be supported by the system as long as the intermediate voltage support is available. Loss of intermediate voltage support will make a stable system unstable. Loss of intermediate voltage support at McNary probably resulted in August 10, 1996 disturbance. A view of the voltage phasor showing

the voltage angle and the magnitude can help the operators to quickly identify the likely cause of instability in the system.

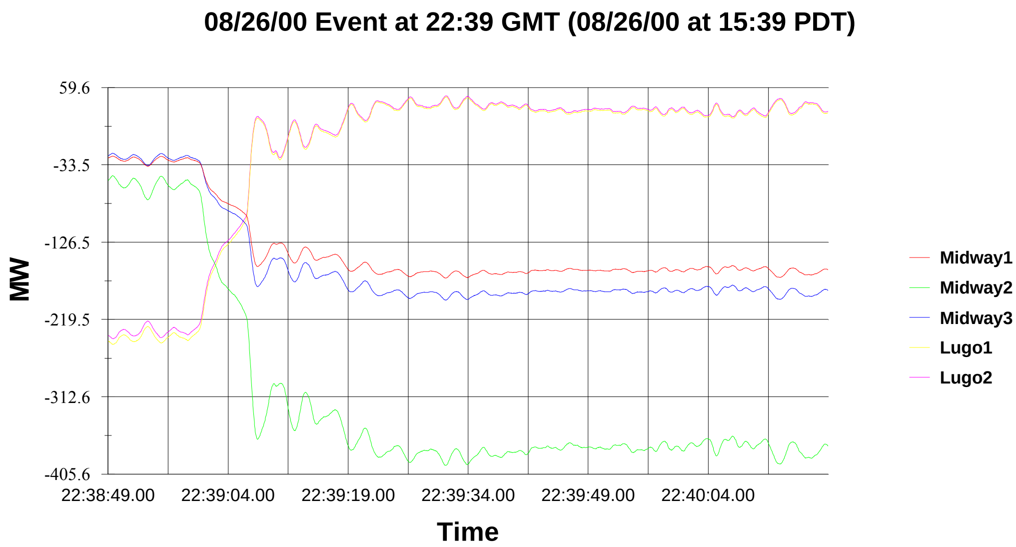


Figure 4- Power flow on the 500 kV lines out of Vincent substation. Most of the disturbance between north -south is contributed by generating units east of SCE Lugo substation.

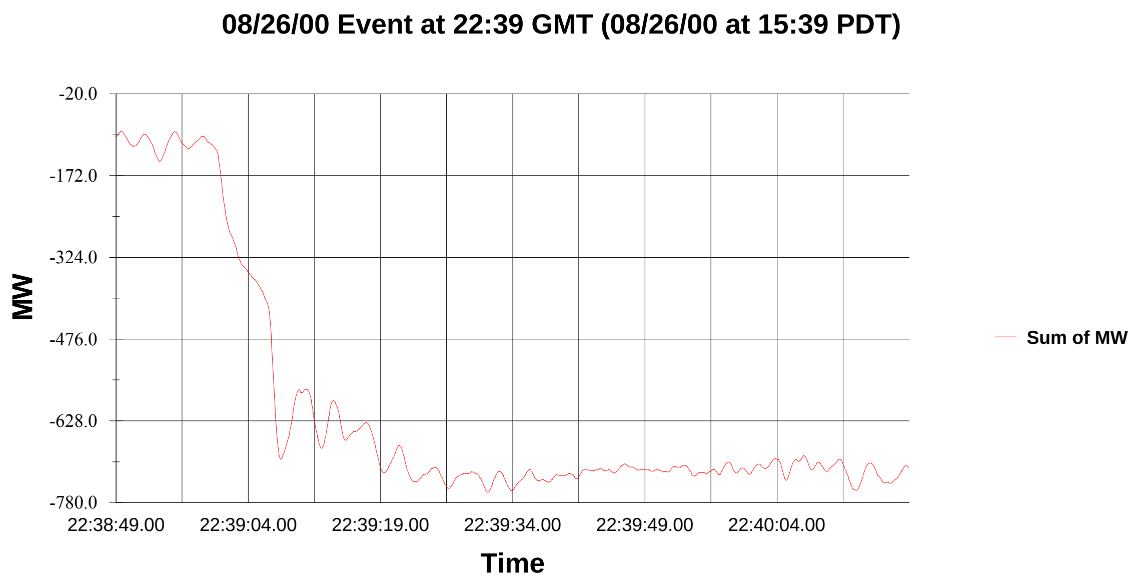


Figure 5 - Cumulative power flow on the Midway-Vincent 500 kV lines. This plot shows the total power swinging between Southern California and Northern California on the AC Pacific Inter-ties.

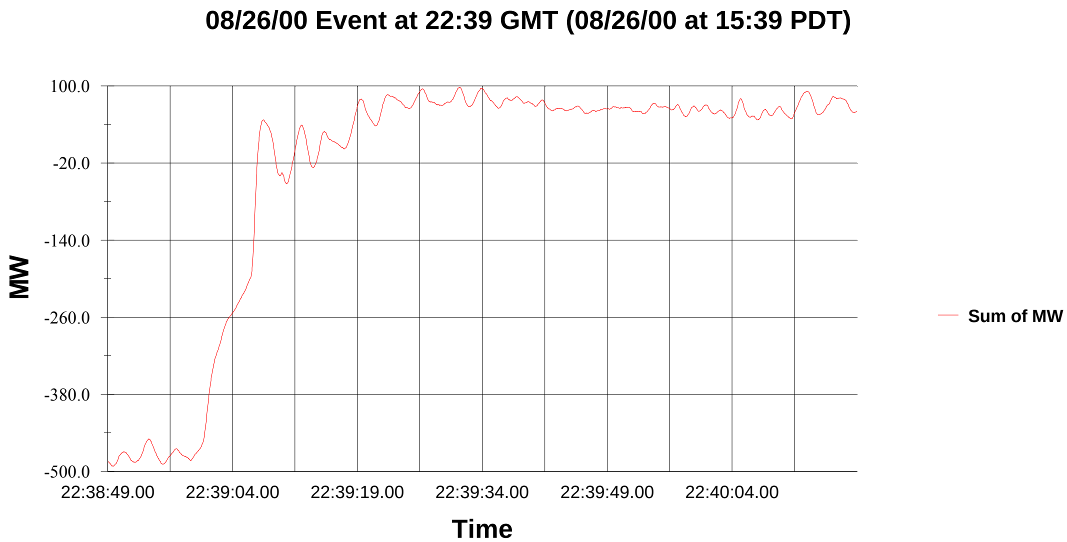


Figure 6 - Cumulative power flow on the Vincent -Lugo 500 kV lines. Power imports to Vincent substation reduced from about -450 MW to export of about 70 MW, a net change of about 520 MW.

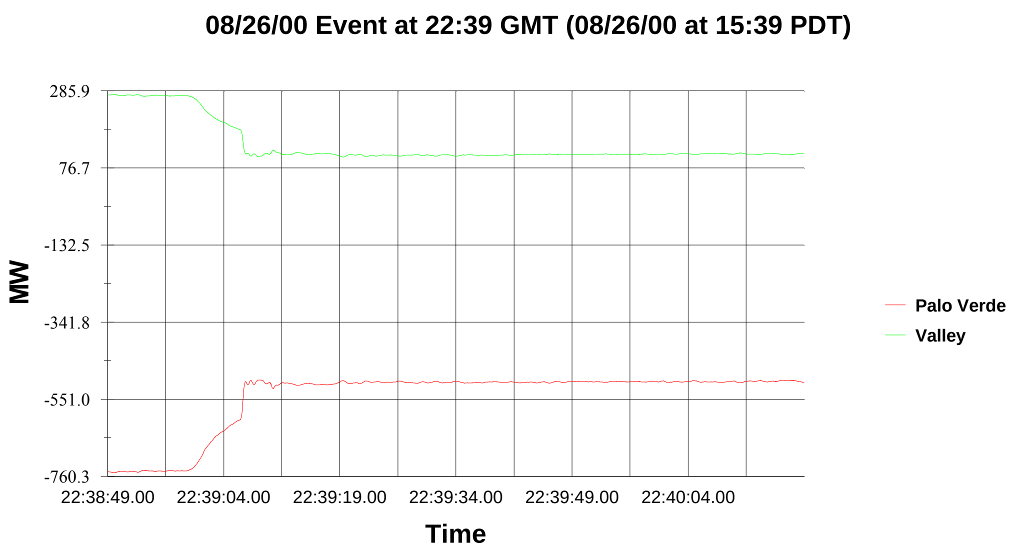


Figure 7 - Power flow on the Palo Verde-Devers 500 and Devers-Valley 500 kV lines at Devers 500 kV substation. The power flow reduced by about 350 MW from Palo Verde and about 200 MW to Valley substation.

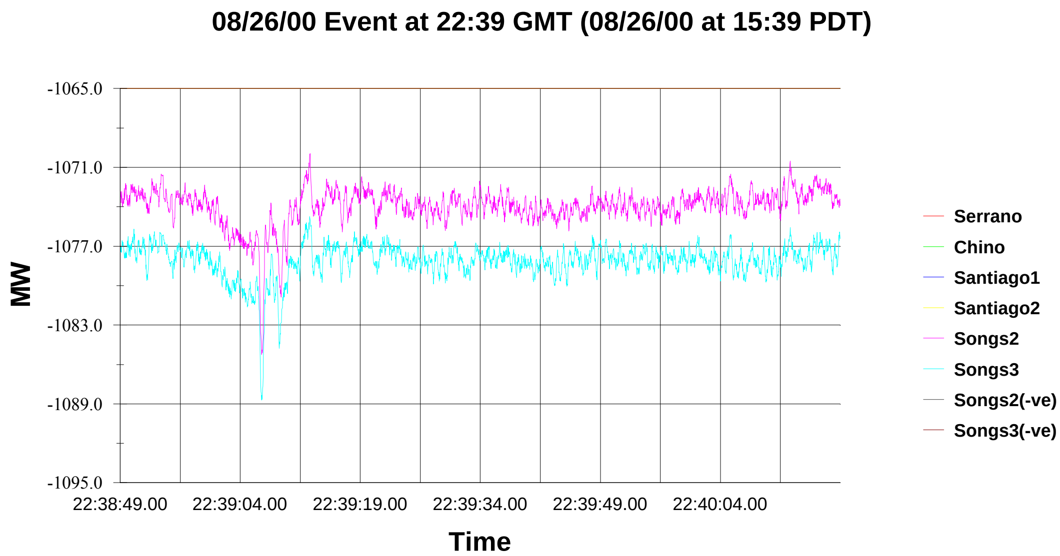


Figure 8 - Response of SONGS generating units to the disturbance. The units appear to be running at full load and the governors do not seem to have responded to the lower frequency of the system.

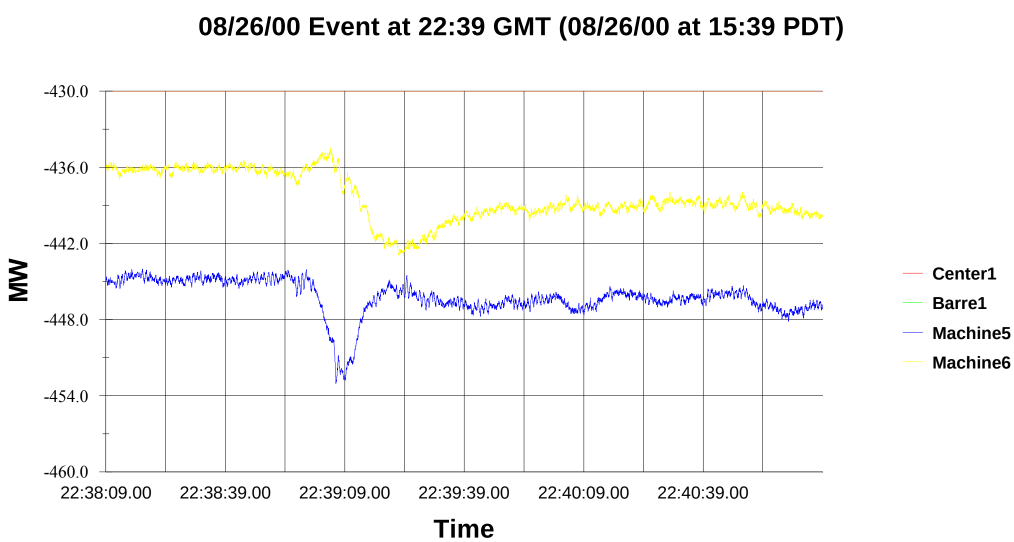


Figure 9: Response of Alamitos generating units 5 & 6 to the disturbance. The governor on unit 6 responded to the lower system frequency, but the unit 5 governor did not change the load on the unit probably because the unit is already running at higher load.

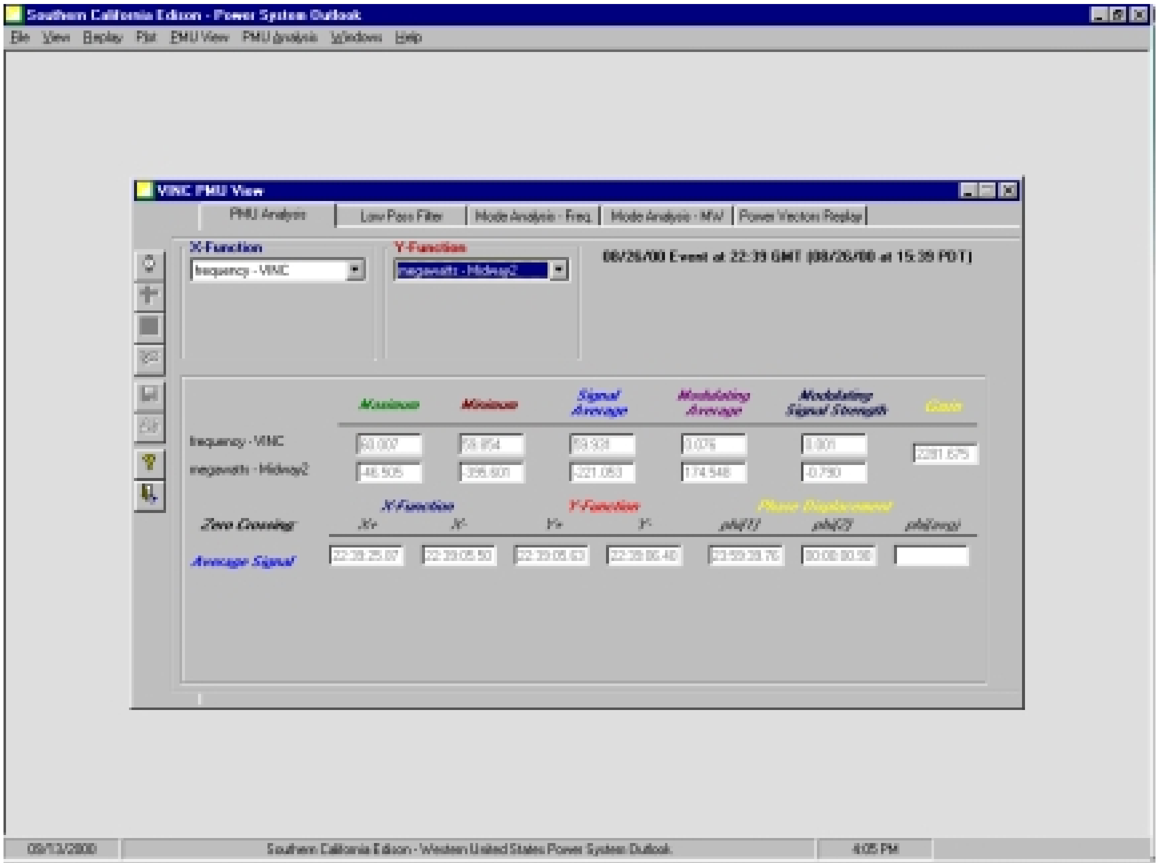


Figure 10 - Screen showing the PSO capability to calculate relationship of one function (X) as against the other function (Y). In this specific display, the relationship of line MW changes with respect to frequency changes are being calculated. This displays the stiffness factor (MWs/per Hz) for the line. This screen can be used to calculate the changes of load, generation with respect to frequency or MVAR with respect to voltage for the disturbance file.

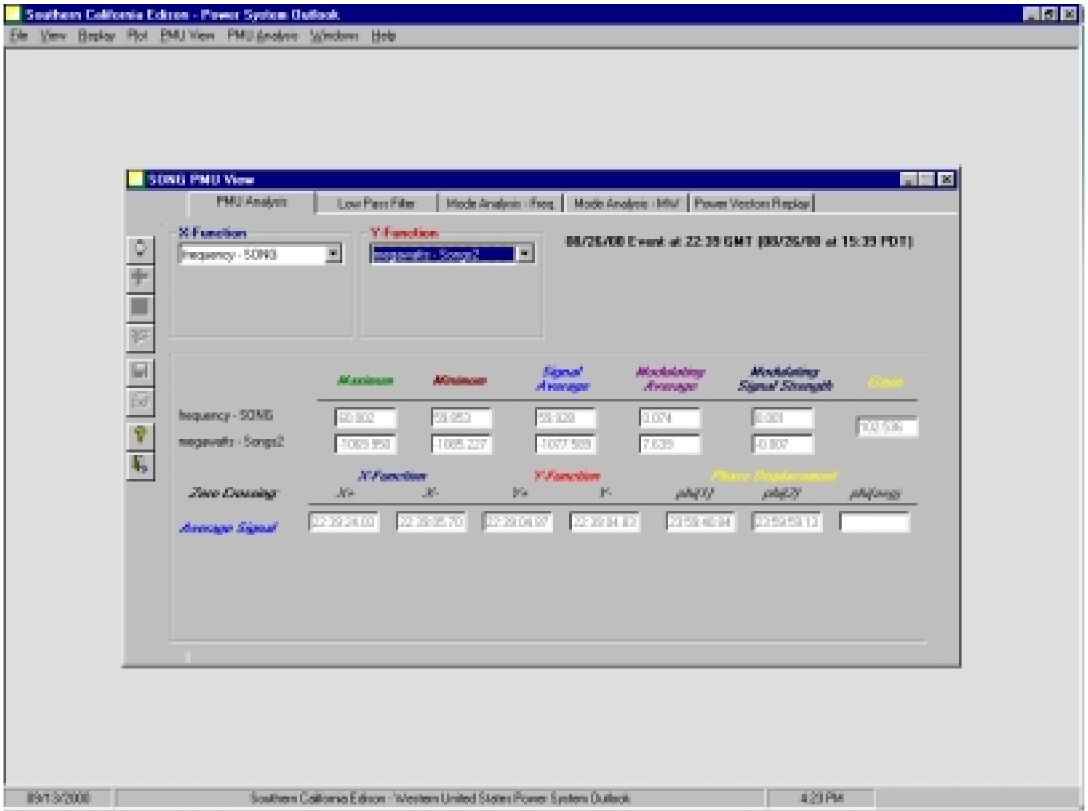


Figure 11 - Screen showing San Onofre unit generation change with respect to the frequency.

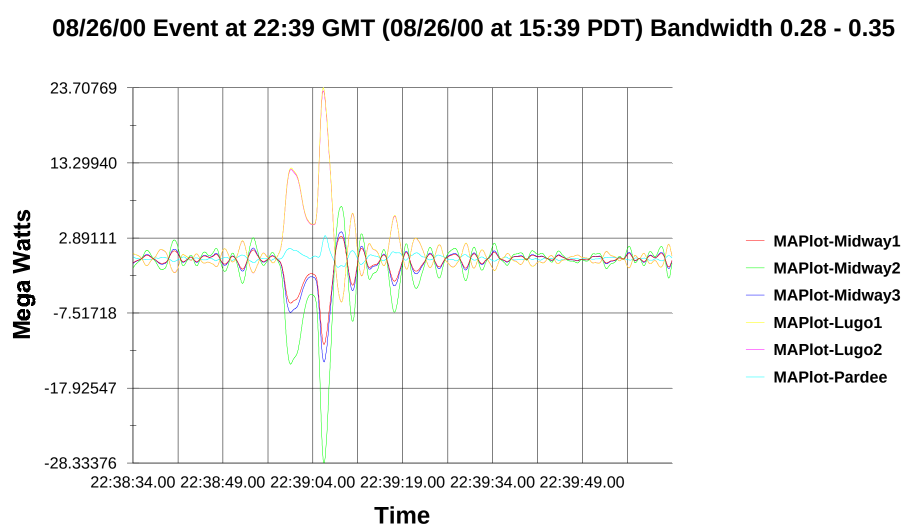


Figure 12 - Plot showing the filtered output of the 500 kV and 230 kV lines at Vincent substation in the frequency range of 0.28 to 0.35 Hz. Oscillations in a specific frequency range can be isolated to determine if they are un-damped and growing or damped. The damping ratio can also be calculated.

ATTACHMENT B

WSCC Plan for Dynamic Performance and Disturbance Monitoring

Final for Approval

Revised September 15, 2000

Disturbance Monitoring Work Group

Bill Mittelstadt (BPA) Chair

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WSCC Plan for Dynamic Performance and Disturbance Monitoring

1. Background

This Plan for Dynamic Performance and Disturbance Monitoring represents the WSCC Plan for Performance Monitoring, and is intended to be updated and revised biennially as needed to be kept current with system needs.

The North American Electric Reliability Council (NERC) has established standards and measures related to required disturbance monitoring. These are described in Attachment 6. The WSCC has been long active in this area and is formalizing these efforts by a plan set forth by this document

In the WSCC there are many aspects of dynamic performance that can only be learned through direct measurements. This need has led to facilities, technologies, and practices in the WSCC that are designed for general performance monitoring, and that provide the basis for an evolving dynamic information network that spans much of the Western Interconnection. The subject of *disturbance monitoring*, for which the NERC has recently established standards and guides, is best addressed by the WSCC within the broader framework of *performance monitoring*. This document is written from that perspective.

The WSCC has been very active in performance monitoring, and has defined the state of the art for this in many respects. Much of this activity started some decades ago, at individual utilities with special involvements in long distance transmission. Sustained efforts at the WSCC level began with the 0.7 Hz Ad hoc Work Group (1988-90), and were broadened under the successor System Oscillations Work Group, or SOWG (1990-1994). These efforts identified better access to dynamic information as a strategic necessity for maintaining the reliability and performance of the Western Interconnection. Working from these WSCC findings, several WSCC utilities joined with the U.S. Department of Energy (DOE) and EPRI in a series of technology demonstration projects under the Wide Area Measurement System (WAMS) effort.

This collective effort has produced many documents based upon WSCC experience and perspectives in wide area measurements, and in performance monitoring in particular. The effort has also produced an explicit technology set, the WAMS technologies, that was designed for WSCC needs and that provides the technology base for most of the wide area monitoring facilities now in service there.

Much of this work is being done without an up-to-date plan of action that has been formally recognized and endorsed at the WSCC level. While a great deal of relevant documentation exists, much of this is broadly focused and some of it is fairly old.

2. Functionalities in Monitor Systems

The power system contains many devices that can serve as monitors for some processes and purposes. This document narrows the field somewhat, through the following definition:

> ***"A monitor is any device that automatically records power system data, either selectively or continuously, according to some mechanism that permits the data to be retrieved later for analysis and display."***

Comprehensive monitoring of a large power system is a long step beyond the monitoring of local devices or even regional performance. Developing a suitable plan of action calls for close attention to emerging information needs and information technologies. Timeliness of the information is becoming an increasingly important consideration. Market deregulation encourages more aggressive use of power delivery assets, and this may lead to progressive encroachment upon customary operating margins. Such considerations, along with challenges in system modeling, can greatly increase the need for direct evidence concerning the proximity and nature of safe operating limits.

Measurement systems, and the monitor systems within them, are a major component for the "defense in depth" approach that the WSCC uses to assure system reliability. Their applications include

- **Real time determination of transmission capacities**, assuming necessary progress with mathematical tools. This will provide the operators valuable information on system security to complement on-line security tools.

- **Early detection of system problems**. This enables cost reductions through performance based maintenance, and provides a safety check on network loading.

- **Refinement of planning, operation, and control processes** essential to best use of transmission assets.

The WSCC planner's operators and Security Coordinators provide benefit as an enterprise network, or "people net," for coordinating monitoring activities among the utilities. This can be very important in dealing with system emergencies, and in the engineering reviews that follow major disturbances or system tests.

Overall WSCC measurement facilities must support:

- Real-time observation of system performance
- Recording and analysis of system disturbances
- Direct tests for purposes such as:
  - validation & refinement of planning models
  - commissioning or re-certification of major control systems
  - special investigations of dynamic performance

From a functional standpoint, the monitor facilities must provide the following functions. Generally all of the requirements are not fulfilled by a single instrument.

- **Disturbance monitoring**: usually characterized by large signals, short event records, moderate bandwidth, and straightforward processing. The frequencies of interest usually extend from zero Hz to an upper frequency in the range of 2 Hz to perhaps 5 Hz. Operational priority tends to be very high.

- **Interaction monitoring**: characterized by small signals, long records, higher bandwidth, and fairly complex processing (such as correlation analysis). Highest frequency of interest ranges to 20–25 Hz for rms quantities but may be substantially higher for direct monitoring of phase voltages and currents. Operational priority is variable with the application and usually less than for disturbance monitoring.
- **Substation fault and event monitoring:** defining the timing and sequence of defining switching from fault onset through line clearing, remedial action scheme operation, reactor and capacitor switching and other events. Digital fault recorders, sequence of events recorders and related devices, which offer high-speed sampling for short duration, provide this capability at the substation level.

WSCC experience argues that disturbance and interaction monitoring functions are best addressed by systems that record continuously, with support by standardized toolsets that extract and distribute the information as needed. Sequence of events monitoring because of the high data rate is generally recorded for triggered events.

3. Elements of the WSCC Plan for Dynamic Performance Monitoring

The Dynamic Performance Monitoring Plan consists of the following elements. Each of these is described in more detail in the following subsections.

1) Classes of Monitoring Equipment and minimum technical requirements
2) Required Locations for Monitoring Equipment
3) Requirements for Testing and Maintenance procedures
4) Requirements for Periodic Review and Re-certification
5) Required Protocols and Formats for Data Exchange
6) Analysis Tools
7) Access to Data
8) WSCC Responsibilities

3.1 Classes of Monitoring Equipment and Minimum Technical Requirements

Classes of WSCC monitoring facilities and technical requirements are detailed in other document.

3.2 Required Locations for Monitoring Equipment

The following locations are important for the purposes of performance monitoring:

Substations on key system interties and major load areas
HVDC lines and links
SVCs, TCSCs and other FACTS devices

Key system generating plants

Special protection systems and remedial action schemes

Measurements shall include relevant quantities depending on location including:

Voltage, current, frequency and phase angle if available
Real and reactive power
Generator PSS, field voltage, field current, gate control
AGC signals to key units
Control signals associated with FACTS and HVDC systems
Circuit breaker status where available as a monitor input
Event or record time (preferably from GPS)

The current list of performance monitoring equipment is provided as Attachments 2-5. This list will be revised as new monitors are added to the system by member utilities. WSCC Committees (PCC/TSS, OC/CMOPS/SCS and OTC Policy Group/Subregional Study Groups) will be requested to recommend any additional monitoring points where coverage is needed. Listing is not required for DFR and SER, which are generally widespread across the system and regularly maintained.

3.3 Requirements for Testing and Maintenance procedures

Testing and maintenance shall be performed based on principles of good utility practices and depending on equipment type, with the objective that all equipment will be operating, properly calibrated and in good working order at all times. A request will be sent out by the Disturbance Monitoring Work Group annually to provide an updated record on the equipment status. A sample is provided as Attachment 7.

3.4 Requirements for Periodic Review and Re-certification

Monitoring equipment, which is tested and maintained per Section 3.3, will be considered as fully certified for the purposes of this plan. New equipment will become certified by providing this information. Based on the information received the monitor equipment lists will be updated by the Disturbance Monitor Task Force annually.

3.5 Required Protocols and Formats for Data Exchange

Protocols and formats shall be standardized so that exchanged data can imported into processing environments such as

Matlab
Excel
Other recognized analysis tools

To the extent possible common standardized formats shall be adopted. Contributors of data that are in binary or special formats are encouraged to provide basic extraction tools that translate their data for use in the processing environments indicated above, and into ASCII.

3.6 Analysis Tools

Analysis tools can range from simple to complex. It is recommended that WSCC members who are engaged in regular analysis of performance data have access to the following capabilities:

Display/plotting of time domain signals for hard copy exchange
Frequency domain analysis
Model fitting to time domain and frequency domain data
Estimation of oscillatory mode parameters
Ability to integrate and compare data from multiple sources (including model simulations)
Archive scanning tools that automatically seek designated types of information
Signal processing tools to examine oscillatory disturbances for warning signs

A general toolset that provides most of these capabilities has evolved through several decades of Bonneville Power Administration (BPA), System Oscillation Work Group, and Wide Area Measurement Systems (WAMS) effort. It is available to the WSCC from BPA, and is recommended as a prototype or template for developing a standardized measurements workstation. The Disturbance Monitoring Work Group will maintain a list of recommended monitoring tools and data formats.

3.7 Access to Disturbance Data

The WSCC will establish a means for providing access to system disturbance information and analysis tools. The methods used will be developed by the Disturbance Monitoring Work Group and submitted to the WSCC Operations Committee and Planning Coordination Committee for approval. This will include instructions for posting of data by monitor site hosts.

3.8 Regional Member Responsibilities

- Provide a list to the Region of their disturbance monitoring equipment that is installed and operational (Measure 2 compliance).
- Maintain a database of disturbance monitoring equipment installations (Measure 3 compliance).
- Provide to the Region system fault and disturbance data (Measure 5 compliance).
- Use recorded data to develop, maintain, and enhance steady state and dynamic system models and generator performance models (Measure 6 compliance).

3.9 WSCC Responsibilities

The WSCC Plan for Dynamic Performance and Disturbance Monitoring will be approved by the WSCC Operations Committee, Planning Coordination Committee, and Board of Trustees and updated biennially. The Disturbance Monitoring Work Group shall have the responsibility for overseeing revision of the plan, compiling and maintaining required databases for the Region, recommending WSCC budget items and drafting other procedures as required. WSCC responsibilities include:

- Updating the plan biennially (Measure 1 compliance),
- Updating the list of monitoring locations on a Regional basis biennially (Measure 2 compliance),
- Establish requirements for providing disturbance monitoring data (Measure 4 compliance),
- Maintain and annually update database of recorded information (Measure 5 compliance),
- Development of analysis tools (Section 3.6),
- Provide general training in use of analysis tools (Section 3.6),
- Keeping a record of active performance monitoring equipment (Section 3.2),
- Testing, maintenance, and certification of monitoring equipment (Sections 3.3 and 3.4),
- Establishment of a means for access to monitor data and analysis tools (Section 3.7),
- Facilitating the recording of data during system tests, and
- Budgeting for the cost of important elements of this plan of common value to WSCC.

This plan meets the requirements for Measure 1. The next revision of this plan shall be completed by August 2001 and thereafter biennially. Measures 2-6 are included as part of the NERC Phase III Pilot program. Requirements for such items shall be completed by August 2001 to the meet Phase III compliance schedule.

4. Glossary of Terms

DSM	Dynamic System Monitor
FR	Fault Recorder
MAPP	Mid-Continent Area Power Pool
PDC	Phasor Data Concentrator
PMU	Phasor Measurement Unit
PPSM	Portable Power System Monitor
PSAM	Power System Analysis Monitor
SER	Sequence of Events Recorder
WAMS	Wide Area Measurement System

Disturbance/Performance Monitor Siting Requirements

1.0 Background

This document details criteria for determining necessary locations for dynamic system monitors. These are considered by WSCC to be essential to provide adequate monitoring for real-time monitoring, disturbance analysis, model validation, system test observation and analysis purposes. This document is a supplement to the WSCC Plan for Dynamic Performance and Disturbance Monitoring and provides specifics as to required monitor locations.

2.0 Desired Observable System Behavior

- Inter-area oscillations and damping control performance
- Local instabilities
- Frequency excursions and governor performance
- Voltage excursions and exciter performance
- Generator reactive responsiveness
- Remedial action scheme function
- System load characteristics

3.0 Monitor Coverage:

The following siting locations are considered necessary to capture the above performance features:

Dynamic Control Devices
HVDC, FACTS and Transient Excitation Boost (TEB) devices. This includes HVDC lines and links; SVCs, TCSCs, and other FACTS devices.

- Voltage, current, frequency and phase angle if available
- Real and reactive power
- Control quantities (if used for fast ramping, modulation, or other dynamic control functions)

Remedial Action Schemes
Key system remedial action schemes for which failed or misoperation could result in system cascading.

- Control signal operations and timing

Transmission Facilities
Voltage and flow on bulk system transmission lines identified as natural break points for system islanding scenarios or as major area interconnections.

- Voltage, current, frequency and phase angle

- Real and reactive power

Generation Facilities (plant rating>200 MW)
Monitoring of generating plants to ensure proper operation of voltage control, frequency control, and power system stabilizers function. Quantities monitored shall include:

- High or low side MW, MVAR, voltage and frequency

4.0 Phasor Measurement Network (PMN) Coverage

This portion involves developing monitor capability at key locations in support of dynamic security measurements valuable to the Security Centers (California, Northwest, Rocky Mountain) and RTO/ISOs. Locations selected would be of sufficient breadth to support system performance indicators including damping, voltage stability, stress angles, and other quantities under development. Initially these measurements would be set up for local collection and as security indicators develop they would be integrated together at appropriate points by Phasor Data Concentrators (PDCs) for transmittal to the Security Centers. Data shall be collected at a uniform sampling rate of 30 Hz and be time tagged. Presently PDCs are in use or under implementation at several locations. Dynamic system security indicators are under development at this time. Phasor measurements are based on point-on-wave sampling of voltage and current.

5.0 Local Monitor Network (LMN) Coverage

Local monitors collect data that is not required for real-time monitoring but is necessary for event analysis and model validation. Collected data shall be archived and time tagged so that it can be aligned with data collected locally at other sites or with archived PMN data. Its sampling rate shall be such that it can be aligned with PMN data without interpolation. Local monitors shall be capable of capturing not less than 30 seconds before a captured event and not less then 120 seconds after. This may be accomplished by sensitive triggering algorithms or by continuous recording, with suitable archiving of files for later retrieval. If monitors are connected to transducers the bandwidth should be such as to provide minimal phase lag up through 5 Hz.

6.0 Proposed Phasor Measurement Network Siting Locations

Transmission Facilities (by Path)
Measurements would be taken to provide an adequate characterization of dynamic activity on each of the following paths. This could be done by measurement of selected lines on each path.
Northwest-Canada (Path 3)
Alberta-British Columbia (Path 1)
Montana-Northwest (Path 8)
West of Colstrip (Path 10)
Bridger West (Path 19)
Northern-Southern California (Path 26)
COI (Path 66)
Pacific DC Intertie (Path 65)
Midpoint-Summer Lake (Path 75)

West of Colorado (WOR) (Path 46)
East of Colorado (EOR) (Path 49)
Intermountain Power Project HVDC (Path 27)
Idaho-Montana (Path 18)
TOT2A, TOT2B, TOT2C
Midway-Los Banos (Path 15)
Other paths determined to be required

Generating Plants
All generating plants greater than 1500 MVA.

7.0 Proposed Local Measurement Siting Locations

Dynamic Control Devices
All SVC or FACTS devices with stability control functions
Celilo – Sylmar HVDC line
IPP HVDC line
All HVDC links with stability control functions
Grand Coulee Transient Excitation Boost

Remedial Action Schemes
BPA RAS Controller
PG&E RAS Controller
NE/SE Separation Scheme Controller

Generation Facilities
Generating plants of greater than 200 MVA not covered by the PMN.

Load Areas
Main load area substation voltages and feeders suitable for supporting load dynamic modeling objectives.

8.0 Schedule/Milestones for Implementation

A schedule and milestones for implementation of monitoring facilities will be developed by the Disturbance Monitoring Work Group for approval by WSCC.

9.0 Glossary of Terms

LMN	Local Measurement Network
PDC	Phasor Data Concentrator
PMN	Phasor Measurement Network